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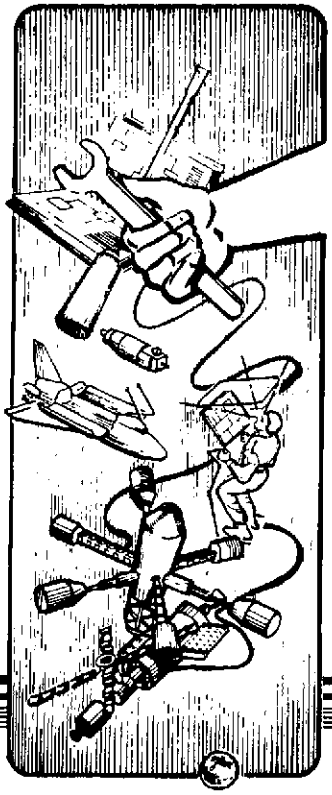

FINAL REPORT

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PHASE III A

CREW INTERFACE SPECIFICATIONS DEVELOPMENT FOR INFLIGHT MAINTENANCE AND STOWAGE FUNCTIONS

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APOLLO AND GROUND SYSTEMS
HOUSTON OPERATIONS

103

FINAL REPORT

PHASE IIIA

CREW INTERFACE SPECIFICATIONS

DEVELOPMENT

FOR

INFLIGHT MAINTENANCE AND STOWAGE

FUNCTIONS

Submitted in Accordance with Data Requirements List
(DRL Line Item #1) of Contract NAS 9-13375

PREPARED BY

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FINAL REPORT

PHASE IIIA

CREW INTERFACE SPECIFICATIONS

DEVELOPMENT

FOR

INFLIGHT MAINTENANCE AND STOWAGE

FUNCTIONS

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PHASE IIIA

ABSTRACT

This report presents the findings and data products developed during the Phase IIIA Crew Interface Specification Study for Inflight Maintenance and Stowage Functions, performed by General Electric for the NASA, Johnson Space Center, under Contract NAS 9-13375 with a set of documentation that can be used as definitive guidelines to improve the present process of defining, controlling and managing flight crew interface requirements that are related to inflight maintenance (including assembly and servicing) and stowage functions.

During the Phase IIIA contract period, the following data products were developed:

- Projected NASA Crew Procedures/Flight Data File Development Process
- Inflight Maintenance Management Process Description
- Preliminary Draft, General Specification, Inflight Maintenance Management Requirements
- Inflight Maintenance Operational Process Description
- Preliminary Draft, General Specification Inflight Maintenance Task and Support Requirements Analysis
- Suggested IFM Data Processing Reports for Logistics Management

The above Inflight Maintenance data products have been developed during the Phase IIIA study after review of Space Shuttle Program Documentation, including the Level II Integrated Logistics Requirements and other DOD and NASA data relative to Payloads Accommodations and Satellite On-Orbit Servicing. These Inflight Maintenance data products were developed to be in consonance with Space Shuttle Program technical and management requirements.

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1.0 INTRODUCTION

This report presents the findings and data products developed during the Phase IIIA Crew Interface Specification Development Study for Inflight Maintenance and Stowage functions in future manned spaceflights. The study was performed by General Electric, Space Division, Apollo and Ground Systems, Houston Operations, under contract with the NASA, Johnson Space Center, for the purpose of developing a set of documentation that can be used as definitive guidelines to improve the present process of defining, controlling and managing the crew interface requirements that are related to inflight maintenance and stowage functions. This study was performed for the Flight Crew Operations Directorate of the NASA, Johnson Space Center, under Contract NAS 9-13375 and has addressed mainly the inflight maintenance aspects of the study topics. The Technical Monitors for the study were Mr. George Franklin (Chief, Operations Support Branch) and Mr. Chris Perner (Chief, Integration Support Section) of the Flight Crew Integration Division.

In previous manned spaceflights through the Apollo Program, there was legitimate reluctance to provide an onboard inflight maintenance capability. Some of the design and operational reasons for this concern were:

a) The capabilities of component reliabilities and subsystems and systems design redundancies to provide acceptable safety margins for the types and durations of the early manned spaceflight missions.

b) Safety concerns associated with having to perform IFM tasks such as trouble-shooting and corrective maintenance while the flight systems were activated.

c) Safety concerns associated with performing maintenance tasks, such as electrical systems checkout and repair, while in an oxygen-rich cabin environment.

d) Consumable budget inefficiencies associated with EVA tasks that required cabin depressurizations and repressurizations where total cabin life support gasses are dumped and wasted.

e) The increased specialized training (technician levels) requirements that would have had to be imposed on flight crews that were already overburdened with normal training demands of the missions.

f) The unknown risks and problems associated with performing maintenance tasks in the zero-g and vacuum environment of free space. These include:

- Problems of translating to worksites
- Stabilization and restraint requirements at the worksites to allow the crewman to apply mechanical torques and forces necessary to perform maintenance tasks
- Management and restraint of loose parts and equipment in zero-g and in free-space
- Life support and safety concerns
- Limitations on manual dexterity imposed by pressure suits

A significant amount of the concern over requiring the crew to perform IFM tasks stemmed from the obvious unknowns related to the environment of free space. With the build-up of operational experience in spacecraft and space suit operations, an increased confidence in the capabilities of crewmen to perform inflight maintenance tasks has developed.

The Skylab missions to date (1, 2 and 3) have dramatically demonstrated the <u>mission</u> and <u>economic</u> values that can accrue from the inclusion of an onboard IFM capability. There have been many examples on these Skylab missions that illustrate the wisdom of having included an inflight maintenance capability. The inclusion of basic tools and procedures (many developed in real time) has significantly increased the return from experiments and has been a major contribution to preserving the operational integrity of the workshop and other cluster modules.

Other factors related to inflight maintenance have also been illustrated by the Skylab missions. One major factor of importance is the fact that all of the Skylab major IFM tasks were <u>planned</u> activities. Even though a significant amount of the planning and preparations had to be done in the haste of the real-time of the mission, the safety and success of these crew IFM operations were largely dependent on the thoroughness of the task and mission planning activities that supported the crew. This thorough planning of IFM activities will continue to be a requirement.

The other IFM factor illustrated by the Skylab program is the major operational advantage that exists in spaceflight operations in the zero-g/vacuum environment of free space versus the atmospheric environment of aircraft operations. Namely, it is possible for crewmen, if properly equipped and supported, to egress outside of the spacecraft and perform the useful work of inspection and repair of their vehicle. The lack of aerodynamic disturbance and resistance in the free space environment allows space vehicles to remain "in formation" with relative ease and with minimal fuel budget impacts. Planning for tethering and/or stabilization of vehicles allows performance of useful corrective maintenance and refurbishing operations either by EVA operations or through the design provisioning of remotely controlled manipulator devices in the maintenance vehicle. It is this on-orbit servicing and IFM capability of the Shuttle orbiter that provides significant potentials for cost savings in many facets of future NASA, DOD and commercial space programs.

The basic inflight maintenance concept or design approach of previous space flights has been not to incorporate inflight maintenance requirements in systems designs unless definite operational and/or cost advantages could justify these requirements. Both the Apollo and Skylab programs have utilized this concept, and in both programs justifications for onboard maintenance have been made such that maintenance tools and spares have been included. These have proved to be of significant value.

A review of the mission experience-to-date on previous manned spaceflights clearly shows that human errors (in design development or mission operations) and equipment failures (random or due to environmental damage) will be ever-present in future space operations and will have definite effects on both mission successes and crew safety. The major issue is not whether an inflight maintenance capability will be developed but rather what degree of IFM capability is technically and economically feasible for future manned spaceflight programs.

The near-future manned spaceflight program (Space Shuttle) will be focused on near earth orbital operations. These Shuttle orbiter missions will permit rescue concepts similar to those of the Skylab program. Missions will be shorter than those in the Skylab program. This will allow most maintenance operations to be performed as a part of the ground operations and during mission turnaround. However, the reuse of space vehicles and payloads will be a new operational dimension that will increase the possibilities for inflight equipment failures and mission contingencies. In addition the continued emphasis on the economic efficiencies will still stress the importance of obtaining maximum scientific and operational returns from all missions. As a result, inclusion of some degree of IFM capability for the basic orbiter vehicle will be required even though the major area requiring IFM planning will be the satellite on-orbit servicing activities. This area will require thorough technical planning in which operational interfaces between the orbiter, manipulator, and payloads are thoroughly understood as well as the operational requirements related to removal and replacement of satellite modules in free space.

It is the above noted areas of concern that are the basic subject matters for investigation during the Phase III Crew Interface Development Study. Phase IIIA of this study has addressed development and specification of a recommended management process to support program IFM activities and the development of task analysis techniques and related resource requirements documentation to support engineering, logistics and operations functions.

2.0 SUMMARY OF RESULTS

The results and data products of the General Electric, Apollo and Ground Systems, Houston Operations, Phase IIIA Crew Interface Specification Development Study on Inflight Maintenance and Stowage functions are summarized in the following paragraphs of this section and in subsequent sections of this report.

The primary purpose of the Phase IIIA study was to extend the inflight maintenance studies of Phases I and II and to begin development of specifications related to future inflight maintenance requirements for manned spaceflights.

The following data products and drafts of NASA Specifications were developed and delivered during this Phase IIIA study contract.

- Projected NASA Crew Procedures/Flight Data File Development Process
- Inflight Maintenance Management Process Description
- Preliminary Draft, General Specification, Inflight Maintenance Management Requirements
- Inflight Maintenance Operational Process Description
- Preliminary Draft, General Specification, Inflight Maintenance Task and Support Requirements Analysis
- Suggested IFM Data Processing Reports for Logistics Management

The draft specification for Inflight Maintenance Management requirements is discussed in Sections 3.0 and 4.0 of this report. Discussion of the other draft specification (Inflight Maintenance Support Requirements Analysis) is included in Section 5.0). These specifications are presently being reviewed by the technical monitors. The analyses and development work associated with the other data products are discussed in subsequent paragraphs of this section.

Recommendations are presented in Section 5.0 for the further development of data product specifications supporting crew inflight or inspace maintenance requirements.

3.0 INFLIGHT MAINTENANCE MANAGEMENT PROCESS DEVELOPMENT AND DESCRIPTION

One of the major guidelines for all phases of the Crew Interface Specification development study has been to maintain a measure of continuity and consonance with presently implemented NASA and contractor management and engineering practices while evolving new concepts for supporting inflight crew activities in future manned spaceflight programs. The purpose of such a guideline was to focus study efforts on development of evolutionary methods concepts that could be implemented on in-progress programs and as such must be in consonance with the management and engineering practices of these programs. As a result, the study activities of the Phase IIIA program have involved detailed examination of methods and practices used by NASA on the Apollo and Skylab programs as well as investigation of the new mission management and operational concepts of the Space Shuttle Program as they apply to the performance by the crew on inflight maintenance tasks on Shuttle orbiter type vehicles, their payloads (fixed or free flying), and space station type modules.

Crew inflight maintenance tasks and support activities were included as subject matter for these crew interface studies due to the unique aspects of the space environment that, if utilized, can contribute significantly to increased mission safety and success of future space programs. As noted in the introduction, the Skylab mission has provided many objective demonstrations of the value of this inflight maintenance capability. However, an even more important reason for an inflight maintenance capability is contained in one of the basic mission objectives of the Space Shuttle program: to provide new economies for both manned and unmanned space operations through the deployment,checkout, on-orbit servicing, and retrieval of payload satellites. This mission objective is designed to significantly expand the space user community through providing more economical mission capabilities for the NASA, Department of Defense and commercial payload developments. These economies largely will derive from the "reuse" mission concept for both the space shuttle orbiter vehicle as well as payloads. The "reuse" concept becomes a viable mission capability largely through the new program facets associated with vehicle design and the planning and provisioning for <u>ground maintenance and refurbishment.</u> Well planned and applied ground maintenance and checkout operations will be the major means for extending vehicle reliability for safe operations. However, <u>inflight maintenance</u> operations will continue to provide contingency capabilities for safety and mission success but more important will provide a new operational dimension for space flight through the on-orbit servicing of payloads.

With an expanded user community that will have responsibility for their own payload design, development and operations, will come new process and methods requirements for support of inflight maintenance tasks.

Following the guidelines for the Crew Interface Specification studies, the Phase IIIA study effort addressed the development of an inflight maintenance process concept for future space programs. In Phase I and Phase II detailed review of both air force and navy maintainability programs were conducted and were reported on in the Final Reports of these studies. Results of these studies need not be repeated but some background data on these DOD Maintainability Programs appears appropriate for inclusion in this report.

Maintainability, as a discipline within the science of engineering, was recognized formally by the military services in 1954 and formal program specifications were available in 1959. The maintainability concept evolved from the results of reliability studies of the 40's and 50's which indicated 100% reliability of equipment was an unobtainable goal and maintenance requirements could not be eliminated. The impetus for the development of maintainability programs came from the realization that operational and program support costs had become the major cost element in weapon systems costs. In an effort to reduce maintenance costs, methods of designing systems for their ease of maintenance during the design phase and of defining requirements for maintenance and operational support, including personnel and training, were developed and identified as integral elements of these maintainability programs.

In view of the above guidelines and background data, the Phase IIIA IFM process development task began by reexamining the methods and techniques being used on DOD missile and aircraft programs of similar complexity. These programs had been researched and reported on in some detail in the Final Reports of the two previous phases of this study. However, detailed study was made of analytical formats and techniques being employed to determine the appropriateness of these techniques in view of the new economics being defined for the Space Shuttle program.

About midway through this Phase IIIA contract study period the Integrated Logistics Requirements, Level II Program Requirements (MSC 07700) Volume XII, was released by the NASA and was reviewed by GE. This document defines the program requirements which are to be controlled by the Program Manager (Level II) and identifies the logistics and ground maintainability program requirements for the Space Shuttle program. Comparisons were made of these requirements with those of the DOD maintainability programs and they reflect technical and management elements that are closely parallel. All elements, having relevance for the inflight maintenance process (though addressing ground maintenance only) were included in this Space Shuttle Integrated Logistics Requirements document. As a result it was used as the basic process structure around which the Inflight Maintenance Management Process was developed. Since it is important to understand the technical and management interfaces between the ground and inflight maintenance processes, the relevant elements of the Space Shuttle

Maintainability Program have been included as an integral requirement of the Inflight Maintenance Management Process Description chart that is presented in Figure 1, Appendix A.

Two additional space program process activities were researched and examined for relevance to the IFM processes on future space programs prior to the formalizing of the Phase IIIA concepts for the Inflight Maintenance Management Process. The processes reviewed included the IFM task and support requirements provisioning of the Skylab program and the crew procedures organization and development process utilized on that program. The planned as well as contingency inflight maintenance experience with the Skylab cluster systems and experiments is the most extensive example to date of an Inflight Maintenance Program. Therefore, review of these processes was felt necessary to the evolution of an IFM Management Process for future programs.

The Skylab Program had unique mission and equipment requirements that resulted in the eventual inclusion of a significant IFM capability. These included:

(1) Systems Design Guidelines that stipulated "No Inflight Maintenance" requirements unless justified through design and analytical trade-offs.

(2) Multiple Spacecraft Modules that were designed and manufactured by different prime contractors. Integration of IFM requirements was accomplished by an integrating support contractor.

(3) Relatively severe weight limitations that forced the optimization of inflight support activities that required additional equipment, weight and storage requirements.

(4) Optimized tool and spares inventories due to the weight limitations.

The Skylab IFM program was examined in detail and in general the methods and techniques used were closely analogous to those management and technical requirements noted in DOD and NASA Ground Maintainability programs. In summary, the IFM program included:

(1) Identification of candidate IFM component items. (This was done from contractor reliability and design trade-offs that established the need for consideration of IFM as a means of meeting reliability requirements.)

(2) Definition of the related support requirements for the candidate IFM item. This included tools, spares, part numbers, and stowage locations. Data on recommended quantities and approved quantities was also included.

(3) A qualitative priority grouping and rating of tasks based on Criticality, Probability, Redundancy, Alternate Operating Modes, Complexity, Mission and Crew Effects.

An evaluation of the applicability of these Skylab IFM program concepts for future programs was made. In general, it appears that the basic process used and the content of the documentation is generally sound but inefficiently formatted. The documentation concepts basically serve the purpose of identifying the additional IFM support equipment required and are useful to the logistics, stowage and provisioning disciplines.

This Skylab task support documentation only identified the need to develop detailed procedures. Little data of value for development of sequential step-by-step procedures was included. The inclusion of more detailed task data as well as application of knowledge gained in Skylab tool and spare provisioning may prove of value in future programs and could reduce the occurrence of problems similar to those encountered with crew procedures verification and flight application on the Skylab program caused by tools that were not adequate for the tasks required. Subsequent operational experience on the Skylab missions have indicated that engineering effort to optimize tools based upon planned tasks only was inappropriate. Namely, Skylab inflight contingency maintenance to lower levels than planned has created a need for tools that were deleted because of no planned task requirement. It appears that standard sets of off-the-shelf tools may be a better approach to tool support provisioning than attempting to finely optimize the tool inventory for the planned IFM activity.

The support effort necessary to coordinate and integrate both the equipment support and crew procedures support for IFM tasks suggested one additional area of research (Flight Crew Procedures Development Process) was required prior to establishing the recommended IFM management process structure. Of particular interest was the manner in which procedures for IFM tasks were categorized and integrated into the flight crew operational procedures. Figure 1 contains the basic organizational structure of the crew operational procedures as they presently are arranged in the Skylab Operations Handbook. In addition, definitions of the content of the various classes of inflight procedures are presented. From this data it can be noted that inflight maintenance crew activities fall into two categories:

(1) Normal-scheduled IFM tasks (planned)

(2) IFM tasks - unscheduled tasks (planned)

SKYLAB OPERATIONS HANDBOOK, VOLUME II
CREW OPERATING PROCEDURES

- NORMAL CREW PROCEDURES
  - NORMAL PROCEDURES
    (CONSIST OF DETAILED CONTROL ACTIONS AND ANTICIPATED DISPLAYS FOR SYSTEMS MANAGEMENT WHEN SYSTEMS ARE OPERATING NORMALLY)

IFM

  - SCHEDULED MAINTENANCE PROCEDURES
    (SCHEDULED MAINTENANCE TASKS REQUIRED TO ASSURE CONTINUED SYSTEMS OPERATION)

- BACK-UP CREW PROCEDURES
  (ALTERNATE OPERATING METHODS FOR USE WHEN A SYSTEM FAILURE OR OTHER ANOMALY PRECLUDES THE USE OF NORMAL TECHNIQUES)

- CONTINGENCY CREW PROCEDURES
  - ABORT PROCEDURES
    (COVER SITUATIONS REQUIRING CREW ACTIONS FOR MISSION ABORTS)
  - EMERGENCY PROCEDURES
    (COVER TIME CRITICAL SITUATIONS THAT PRECLUDE DIAGNOSIS AND DECISION AND REQUIRE IMMEDIATE ACTION TO AVOID OR ALLEVIATE A CONDITION POTENTIALLY HAZARDOUS TO THE CREW)
  - MALFUNCTION PROCEDURES
    (COVER ALL PLANNED CONTINGENCIES OTHER THAN ABORT AND EMERGENCY. PROVIDE FOR SYMPTOM IDENTIFICATION, DIAGNOSIS AND CORRECTIVE ACTION)

IFM

- INFLIGHT MAINTENANCE TASK PROCEDURES
  (COVER THE UNSCHEDULED RESTORATION OR REPLACEMENT OF A DEGRADED OR INOPERATIVE ITEM OR SYSTEM TO ITS NORMAL FUNCTION)

SKYLAB OPERATIONS HANDBOOK
PROCEDURES
ORGANIZATION

FIGURE 1

This separation of the IFM operational procedures into two classes is appropriate for real-time mission operations since the normal-scheduled IFM tasks are performed as an integral part of the basic mission time line. Both classes of IFM crew procedures are preplanned tasks. When the management and engineering process requirements necessary for planning and development of all classes of flight crew procedures (Figure 2) are analyzed, it is apparent that the IFM procedures constitute a unique class of operations requiring many additional design, planning and preparation process elements. These additional requirements for engineering, logistics, and operations program tasks constitute the major justification for considering Inflight Maintenance as a special program discipline or responsibility that requires management attention and should be defined as a planned, organized program process.

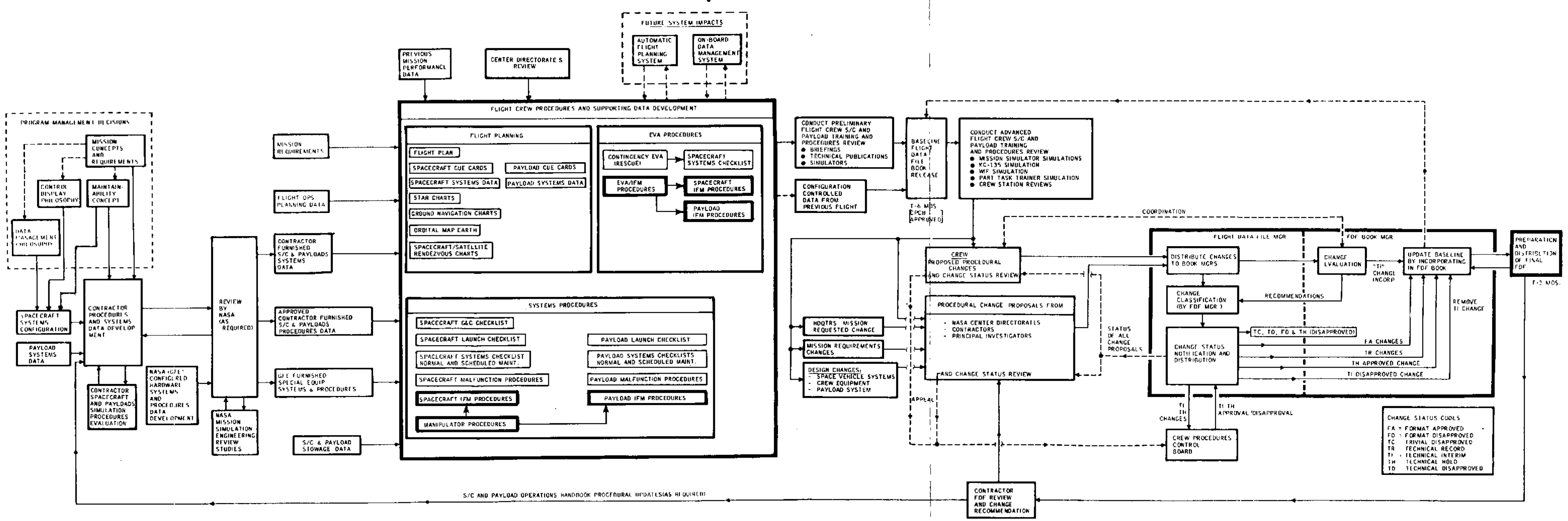
In addition to the flight crew procedures documents review, a reexamination of the development process that produces the flight crew procedures and flight data file (procedural data carried by the crew to support real-time mission operations) was conducted. A flow diagram description of the process that supported the Apollo program space flights and which is presently used in essentially the same form for the Skylab program, was developed during the Phase I Crew Interface Specification Development Study. This process chart was presented on page A-9 of Appendix A of the Phase I Final Report. The process was analyzed and reviewed in light of the early mission concepts and operational plans being released on the Space Shuttle Program. The mission concepts of (1) "reuse" of spacecraft and payloads, (2) ground maintenance and quick turnarounds, (3) on-orbit servicing of payloads, and (4) payload development and management by users other than the NASA will result in a major revision to the program support processes that have been used by the NASA on previous manned spaceflight programs. The anticipated changes to this flight crew procedures/ flight data file development process resulting from these new mission concepts were incorporated into a projected updating of this process description. This projected process description is presented in Figure 3 and contains the process elements (enclosed in darker box outlines) related to the development of IFM procedures for both spacecraft and payloads. It is also important to note that review by NASA of both Spacecraft and Payload Contractor Crew Procedures and Systems Data will be "as required." This is anticipated inasmuch as payload development for the Shuttle program may be conducted by Department of Defense, foreign governments and civilian organizations as well as by the NASA. In addition, principal investigators from these non-NASA organizations will act as crewmen passengers who will be responsible for the operations of the payloads and the performance of most of the IFM tasks that may be required by the payload equipment and experiments. As a result, the formalizing of payloads procedures and the requirement for NASA to maintain a strict configuration management control over both the payload operations as well as IFM procedures may be a

SPACE DIVISION

FLIGHT CREW PROCEDURES CATEGORY	FLIGHT CREW PROCEDURES MANAGEMENT AND ENGINEERING PROCESS REQUIREMENTS											
	DESIGN AND DEVELOPMENT ENGINEERING					INFLIGHT SUPPORT REQUIREMENTS						
	SYSTEM DESIGN AND PERFORM. SPECIFICATION	SYSTEMS CONTROLS/ DISPLAYS PERFORM. SPECIFICATION	PLANNING FOR BASIC MISSION OPS.	IDENT. OF IFM REQ'MTS	INFLIGHT ACCESS AND MAINT.	INFLIGHT CREW PROCEDURES	IFM EQUIP. Δ WEIGHT MGT.	IFM LOOSE EQUIP. STOWAGE PROVISIONS	TOOL DEFIN. AND PROV.	SPARES DEFIN. AND PROV.	IFM LIFE SUPPORT EQUIP.	OTHER IFM AIDS
● NORMAL MISSION OPS.:												
- NORMAL OPS.	X	X	X			X						
IFM - SCHEDULED - INFLT. MAINT. OPS.	X	X	X	X	X	X	X	X	X	X	X	X
● BACKUP OPS.	X	X	X			X						
● CONTINGENCY OPS.												
- ABORT	X	X	X			X						
- EMERGENCY	X	X	X			X						
- MALFUNCTION	X	X	X			X						
IFM ● INFLT. MAINT. OPS. (UNSCHEDULED)	X	X		X	X	X	X	X	X	X	X	X

FIGURE 2

FIGURE 3. PROJECTED NASA PROCEDURES/FLIGHT DATA FILE DEVELOPMENT PROCESS



FOLDOUT FRAME 1

FOLDOUT FRAME 2

mandatory program management requirement. This does not infer that crew, payload interfaces and mission safety considerations will not be mandatory aspects of NASA program management of payloads. Many experimental operations will be performed by principal investigators who will be intimately familiar with the equipment and as long as no safety-of-flight effects could result from these operations, formalized procedures definition and configuration management requirements of these procedures may be waived by the NASA.

The above reported background research and study served as a basis for the development of a recommended NASA INFLIGHT MAINTENANCE MANAGEMENT PROCESS. The process was formalized into a flow-diagram description and related textual description that is presented as an integral part of the recommended Inflight Maintenance Management Specification included as Appendix A of this Final Report. The flow chart definition of the basic Inflight Maintenance Process is presented as Figure 1 of Appendix A and with related textual data satisfies the contract requirements of the statement of work paragraph 3.2.

4.0 INFLIGHT MAINTENANCE MANAGEMENT SPECIFICATION

One of the major tasks of the Phase IIIA Crew Interface Specification Development Study was to develop an Inflight Maintenance Management Specification that will provide definitive guidelines for future spacecraft and payload contractors as to the management processes to be employed and related analytical and data products required to support the design, development, preparations and real-time activities associated with inflight maintenance of spacecraft and related payload equipments and experiments.

The recommended General Specification, Inflight Maintenance Management Requirements that was developed by General Electric Houston Operations to satisfy the Phase IIIA contract requirements of the Statement of Work paragraph 3.3 is included as Appendix A of this report. The specification is presently in review by the JSC technical monitors and other center personnel.

This specification was developed to define a standard process for managing the various facets associated with the new design, development and operational implications of on-orbit servicing of experimental payloads and of performing contingency maintenance on spacecraft in space.

5.0 INFLIGHT MAINTENANCE TASK AND SUPPORT REQUIREMENTS ANALYSIS METHODS DEVELOPMENT

During the research activities of the Crew Interface Specification Study, there has been an examination of the state-of-the-art in management and technical requirements being specified for systems operational effectiveness (i.e., reliability, maintainability, safety, operations and human factors engineering). In all of these disciplines the major emphasis is on development of techniques that will allow for the effective design and planning for operations and maintenance. This emphasis stems from the spiralling costs of the operations of the increasingly complex and higher technology equipment. In fact, the cost of operations had become a consistently larger factor in systems cost than initial procurement costs. Programs that were initiated to examine these operational costs consistently identified problem areas that could be traced to the fact that systems were not being designed for effective operations and maintenance. As a result operations costs had gone up somewhat as a function of the complexity and size of the equipment being operated. The Reliability discipline evolved to develop means of predicting when failures would occur on equipment systems and components. Maintainability programs were developed to monitor systems design to insure consideration of maintenance operational problems. Maintenance engineering activities evolved as detailed examinations during design of maintenance tasks to be performed and their related support requirements. This activity was performed by engineering personnel experienced in maintenance operations as well as human factors and operational engineering personnel who were predominantly interested in safety and efficiency in systems operations and related maintenance activities. The major emphasis being to force the systems designers to use concepts that considered the problems of the <u>users</u> and <u>maintainers</u> of the equipment as well as of the basic equipment engineering requirements.

When the zero-g, vacuum environment of space is considered as a mission environment for a maintenance task, many new operational constraints must be considered as well as the potentials that can be realized from being able to perform tasks outside of the vehicle during inspace operations, either with crewmen in protective suits and/or with manipulator systems. However, the constraints and potentials for inflight maintenance provide an even greater emphasis on early planning and designing of spacecraft systems, payloads and of their inflight loose supportive equipment for inflight or inspace maintenance.

It is with the above concepts in mind that the recommended Inflight Maintenance Management Process (presented in Figure 1, Appendix A) of the Phase IIIA study was developed. More specifically, the related process elements that were included in this IFM process to accomplish the early consideration in the program design phases of space systems development are identified under 4.0 IFM Design Criteria and Task/Support Requirements Documentation of the IFM Management Process. The specification of the IFM Design Criteria for Spacecraft and Payloads Integration (4.1) is intended as a historical documentation of IFM experience from previous manned and unmanned space programs that can be used as guidelines for the design and planning of space systems for the unique operational requirements in the environment of space. This IFM process task requirement was not identified in the Phase II process study but after examining the large amount of relevant operational data on IFM that has been collected from the Skylab program experience, it appears mandatory that an IFM criteria document be developed and maintained as a reference document for future spacecraft and payload design development.

The other major IFM analysis and documentation requirement identified in the IFM management process was (4.2) IFM Task/Support Requirements Analysis. The need for this process element was identified during the Phase II study. The development of a concept for an appropriate analytical method and the subsequent preparation of a recommended specification defining both analytical and documentation requirements for an IFM Task Support Requirements Analysis was one of the major contractual tasks (Paragraphs 3.6 and 3.11 of the Statement of Work) of the Phase IIIA study effort.

As referenced background for development of this study methodology, it was determined that a thorough review of both Skylab program operational experience and the implications of the mission and systems concepts of the Shuttle program should be conducted for the purpose of identifying the anticipated operational requirements for future spacecraft and payloads programs. The results of this major task of the Phase IIIA study were documented in two process flow diagrams that are included in Appendix B, Figure 1 (Inflight Maintenance Operational Functions Analysis Chart) and Figure 2 (Operational Function Analysis of the Basic Inflight Corrective Maintenance Tasks). The purposes served in developing these charts were educational in that future program requirements as well as previous space flight experience could be examined and documented so that flight crew functions related to IFM could be systematically identified. The first diagram was developed to identify the mission elements that define the preventative or scheduled IFM tasks, the troubleshooting or diagnostic functions as well as the basic types or modes of corrective maintenance that are anticipated on future programs. After establishing these modes as well as the operational degrees of freedom associated with each type, an in-depth analysis of these corrective maintenance modes was made to establish the basic task elements that would make up each of these modes. These task elements "Preparation"; "Egress and Ingress";"Translation to Worksite"; "Worksite Stabilization"; "Additional Troubleshooting and Disassembly"; "Corrective Maintenance"; "Verification and Reassembly"; and "Return to Operational Status" were seen to have definable design and equipment implications. To further understand these implications, an analysis was made of a representative IFM type (IPM-2) which required assumption of a spacecraft configuration composed of an orbiter and Sortie Module with experiments pallet. This analysis was documented in the Requirements Allocation Sheets that are included in Appendix B. From this analysis many generic design and support equipment requirements were identified. Many of the requirements are very unique and stem from the unique operational aspects of the space environment. In future spacecraft and payloads development programs, these types of operational considerations must be included as an integral part of the design process and must be an element in the rationale of all subsystems designs.

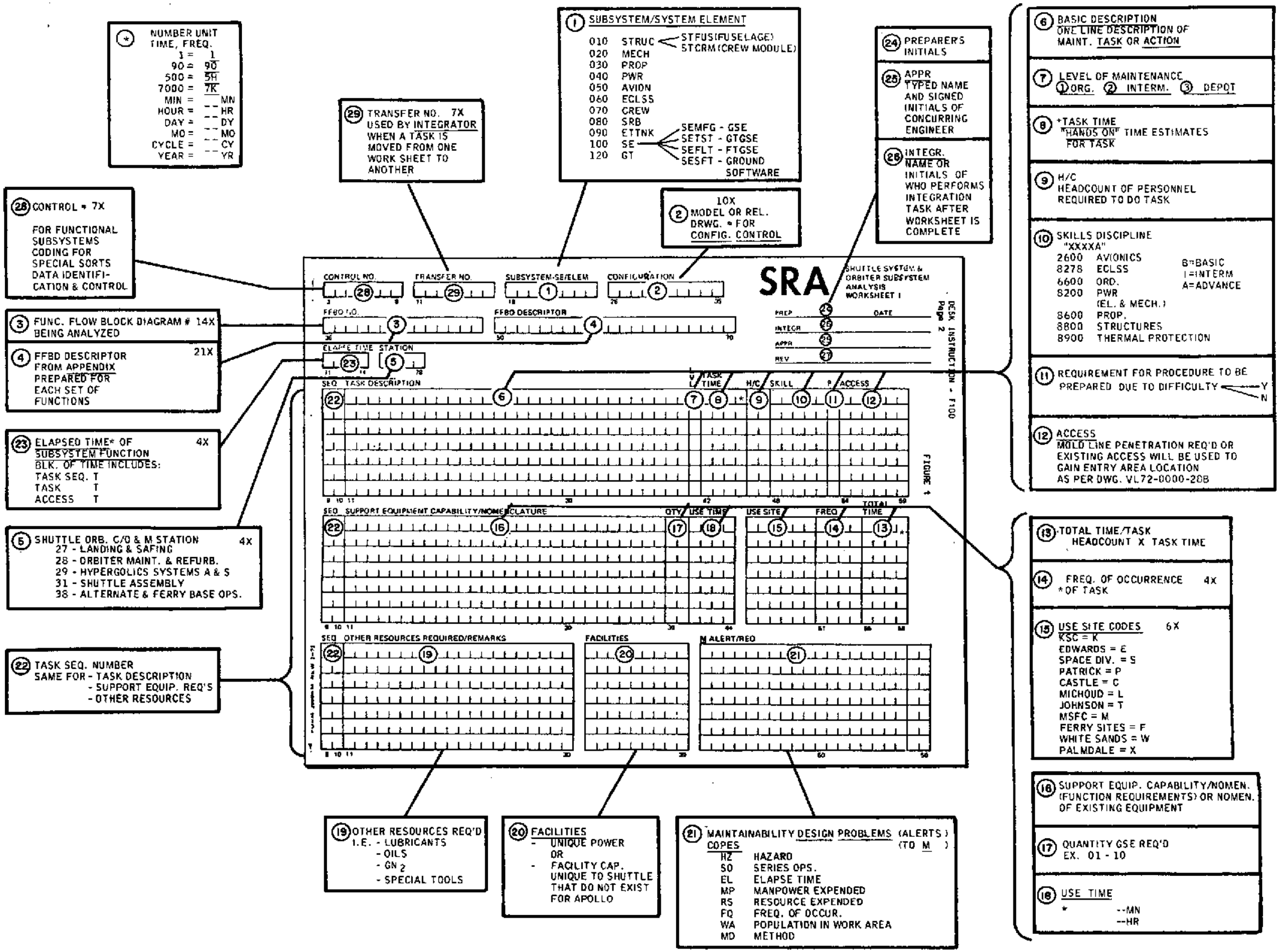
In considering the climate of reduced program costs, a major problem was to define appropriate formal documentation of requirements for a specific mission and design. The function analysis conducted during the Phase IIIA program was very valuable for purposes of early development program information but as a requirement to be placed on all spacecraft and payloads contractors it appears to be excessive in that much of the data will be developed in the existent engineering processes. However, certain basic elements of these analyses did appear appropriate to define as considerations that are mandatory for future programs. Specifically, 1) If an inflight maintenance task is to be required for a specific subsystem component, whether payload or spacecraft, it must be established early that the performance of the task is feasible and that the inflight support requirements are identified and evaluated as to appropriateness from a weight, stowage and operational viewpoint. 2) Implication of each of the task elements or task groups of an IFM task (i.e., preparation, egress, etc.) must be considered so that appropriate support requirements are identified. For example, if tasks are to be performed in free space, a continuous tracking and containment method must be defined for all loose modules, parts, tools, etc. These equipments and procedures must be identified such that a feasible operational concept for each task can be established and then evaluated as to the cost effectiveness of such an IFM concept.

As a result of this functional analysis of IFM, specific documentation requirements have been included as an integral part of the documentation format for the Task/Support Requirements Analysis that was developed during the Phase IIIA Study and included in the General Specification on this subject matter that is included in Appendix C of this report.

As noted in general discussions earlier in this report, one of the guidelines for development of concepts during this study was the requirement that they should be in consonance with inplace or planned NASA management and technical processes. As a result, the Phase IIIA study has included a significant effort to research the newly planned processes of the Maintainability and Maintenance Engineering Program for the Space Shuttle. This program is concerned with the ground maintenance aspects of this project and particularly with being able to accept an orbiter vehicle from a mission; to safe and deservice the vehicle, including payload removal; to accomplish maintenance and refurbishment tasks on the vehicle; and to check out and prepare the vehicle for relaunch within a one-week to ten-day timeline. Obviously, these program requirements will constitute major revisions to present modes of checking out and launching space vehicles. In particular, these new Shuttle orbiter requirements demand the optimization of the ground maintenance activities and have created the need within the early design effort of new formalized management and technical programs. The Maintainability and Maintenance Engineering Program for the Shuttle is addressing this need through design monitoring and formal documentation requirements of analytical efforts designed to identify maintenance tasks and their related support equipments. Figure 4 contains a sample of the basic worksheet documentation format of the Support Requirements Analysis (SRA) that is being utilized presently on the Shuttle Orbiter Project by Rockwell International. This format is of interest not only from an informational standpoint but also as representative of modern methods of processing this data for engineering and management purposes. Namely, this SRA worksheet is designed for easy translation into a computerized data bank from which can be generated many different types of reports specifically designed for user engineering and logistics management purposes. Since these data processing techniques can also be applied in a similar manner for IFM analytical and documentation purposes, this SRA documentation format was used as the basic reference for the Inflight Maintenance Support Requirements documentation (ISRA) worksheet that has been developed during the Phase IIIA study as not only a data processing worksheet with standard data and data entry requirements but also as a method of standardizing analytical activities and identifying basic engineering considerations that must be included as background for the definition of "candidate IFM items" and their related task and support requirements.

The use above of the term "candidate IFM items" warrants some explanatory discussion. In the development engineering activities many design and analytical tradeoffs are necessary within the domain of spacecraft and/or payload subsystems design. These tradeoffs can be adequately effectual without demanding an exhaustive and costly documentation of these design activities. However, when tradeoff studies establish that consideration of inflight maintenance should be made, <u>then</u> the task analysis documentation for these items is required. It is required not only to establish IFM tasks and support equipment requirements but also to establish the weight and

FIGURE 4. SHUTTLE ORBITER SUPPORT REQUIREMENTS ANALYSIS WORKSHEET



SPACE DIVISION

and operational resources that are associated with each IFM item. This support requirements documentation along with other data on criticality of the item, costs, etc. will provide the information basis for decisions on which of the items are to be included within the IFM capabilities of spacecraft vehicles and related payload modules.

The process of establishing a baseline of candidate IFM items was utilized during the Skylab program. An informal program of configuration control of these items was maintained early during design development as well as preliminary lists of IFM tasks/tools/support equipment requirements. The lack of having formal requirements for an IFM program led to numerous inefficiencies in the Skylab program which could have been avoided if a formal process of defining and placing IFM items under configuration control had been established earlier. Nevertheless, when implemented, the Skylab process of planning for IFM was effective and in general a satisfactory IFM capability was provided. For these reasons, IFM process requirements to baseline and track IFM items were included in the recommended specification for future programs as a means of emphasizing the need to include operational aspects of IFM as an integral part of the design decision process that establishes the structure and the magnitude of the IFM capability.

The Skylab program IFM management process was largely affected by the integrating contractor. This was necessary because of the three prime contractors involved in building the Skylab cluster modules. However, data processing techniques were not employed in developing the related logistic lists such as task/tools matrix, spares requirements, etc. This inefficiency largely stemmed from the attempt, with this documentation, to track the "contractor recommended" versus the "approved" support requirements rather than using the in-place configuration management techniques. It is anticipated that in future programs the results of tradeoff studies and activities required to optimize tool and spare requirements will be included as revisions to the basic ISRA data sheets and that the baseline data generated from these sheets will reflect program decisions affecting the IFM capability.

The recommended format for the ISRA sheets is included as Figure 1 of the IFM Task and Support Requirements Analysis Specification that constitutes Appendix C of this report. The format contains the following five basic categories of data:

- IFM Candidate Item Identification Data
- Design Background Data
- Summary Task/Time/Unit Weight Data
- Task Description/Support Requirements Data
- Worksheet Preparation and Control Data

The form in which these data are to be entered on the worksheets, as well as discussions of coding and other technical and analytical data requirements are provided as a part of the IFM Task and Support Requirements Analysis Specification (Appendix C). As a result, no detailed discussion of data elements of these formats will be included in this section of the final report. However, discussion of the unique IFM provisions of the format does appear appropriate. Two data elements of the format (Task Groupings and Support Equipment Type codes) have been included for the purpose of acquainting the analyst with basic subtask groupings of IFM tasks that present uniquely different operational requirements and as a result also different support equipment needs to accomplish the tasks.

In addition the coding system for support equipment provides basic guidelines of various equipment types that are known to be required from previous zero-g operations in space. Figure 5 contains these coding systems. The Task Grouping Codes (Cards "C", "D", Columns 9-10) were derived from the IFM functional analysis that was conducted during Phase IIIA and reported previously in this section. The support equipment codes (Card "D" Column 14) provide identification of the classes of IFM support equipment that present mission experience to date has found to be necessary for accomplishment of tasks in space. By requiring usage of these codes, increased familiarity with problems of zero-g operations can be obtained and greater assurance can be provided to technical monitors that the unique aspects of performing tasks in zero-g and free space have been considered.

Other data elements of these ISRA formats are closely related to the data requirements of the ground maintenance engineering analysis documented on the SRA worksheets. This should reduce training requirements in that analysts performing ground maintenance studies should also be able to perform IFM task studies with only a small amount of additional directions and training. Thus the recommended documentation requirements for IFM have also been designed to relate to the ground maintenance engineering methods just as were the basic IFM process requirements identified in the IFM Management Specification correlated with the Maintainability program requirements.

The ISRA worksheets are designed for ease of key punching and conversion to computerized data processing methods. These worksheets thus serve as the basis for a data base from which can be generated many types of reports that can be of use to program management, logistics and procedural development personnel.

The analysis and documentation effort involved in the Task and Support Requirements Analysis does constitute a substantial engineering effort. Similar methods have usually only been employed on relatively complex systems where the numerous related schedule and design impacts on program development, crew safety and mission provisions could be significant.

FIGURE 5. INFLIGHT SUPPORT REQUIREMENTS ANALYSIS CODES

TASK GROUP CODES:

PR = Preparation
EG = Egress
XL = Translation
WK = Worksite Stabilization
GA = Gain Access
MT = Maintenance Performed
VE = Verification and Test
CL = Close Out
IN = Ingress
RO = Return to Operations

SUPPORT EQUIPMENT TYPE CODES:

C = Containment Devices
I = Illumination Aids
K = Check Lists
L = Life Support
Q = Special Test Equipment
R = Restraints, Tethers
S = Spares
T = Tools
W = Worksite Stabilization Aids
X = Translation Aids

Economic efficiencies could be demonstrated for such analytical efforts, if major hardware design changes late in a developmental program could be reduced.

When one examines future space programs and payloads that are planned, the question arises as to the appropriateness of such analytical documentation requirements for specific payload development programs. This is a matter that must be decided by program management based upon the nature of the payload equipment and mission requirements. For example, if a particular experimental payload involves only the use of equipment such as cameras that have a well established reliability in previous spaceflight usage; and if the basic experiment is of a relatively low priority (e.g., if the data was not obtained no significant scientific or political impacts are predicted to occur); and if the operating procedures are very simple requiring no complex manipulator usage or special EVA by the experimenter crewmen, then detailed Task and Support Requirement Data would appear to be inappropriate. However, if the payload is a high priority relatively complex module with many operational and maintenance interfaces with the Shuttle manipulator that requires designing the payload for compatibility with the operational characteristics of manipulator and spacecraft, then the Task and Support Requirements Analysis is essential and should be mandatory for NASA developed spacecraft and payloads.

The important factor to emphasize about IFM items and tasks is that the implications of operating in the space environment be understood, designed and planned for. If the operating procedures and equipment are simple and reliable then detailed IFM task and support equipment studies can be waived, but if systems designs and operational interfaces are complex, the implications for safety and mission success must be well investigated. The IFM Task and Support Requirements Analysis can be an effective device for establishing requirements and determining the complexity of crew operational requirements.

The NASA management problems involved in imposing the Task and Support Requirements Analysis specification on payloads development programs that are managed by Department of Defense, foreign governments or commercial organizations will be complex. However, even in these circumstances, it appears appropriate for the Task and Support Requirements Specification to be provided as definitive guidelines for their studies and hardware development programs since experience with the unique in-space, zero-g environment requirements is relatively limited.

One additional factor that may influence the emphasis that should be placed on planning for inflight maintenance is the design philosophy that governs future spacecraft and payload design. For example, if inflight maintenance operations are used as a mission mechanism that can be used to offset the risks of in-space operations and consequently allow equipment design reliability requirements to be reduced, then more emphasis must be placed on effective and detailed planning of those inflight maintenance operations involved.

The stowage and loose equipment specification development study conducted during the Phase II study included reviewing the logistics processes associated with the provisioning of loose equipment for flight as well as for test and training activities. This aspect of the IFM support requirements process appeared to involve different disciplines and management areas. As a result, it was felt that the logistics activities of IFM warranted a special specification defining data requirements to support these areas. However, after the Phase IIIA study review of Skylab and Shuttle program data, it was evident that the major IFM logistics requirements could be satisfied with data processing reports that could be generated directly from the Task and Support Equipment Requirements Analysis data base. As a result the IFM logistics requirements have been included as an integral part of that specification which is presented in Appendix C. These reports are related to specific yet generic requirements which will continue to be significant aspects of the IFM management process in future space programs. One concept presents correlation data between task and tool requirements which is used for provisioning as well as crew procedure development. Spares and other support equipment data formats must be reported in summary form for management purposes as well as for stowage and weight management operations.

Support for the Space Shuttle program stowage management and provisioning activities is presently being organized and defined and other data formats may be appropriate for subsequent development. It is recommended that such report formats be defined by GE during the Phase IIIB study if the Shuttle program management and technical processes evolve in a manner that suggests other useful data processing reports are desirable from the Task and Support Requirements Analysis data base.

6.0 INFLIGHT MAINTENANCE TASK AND SUPPORT REQUIREMENTS ANALYSIS SPECIFICATION

The second major data product requirement of the Phase IIIA Crew Interface Specification Development Study was the Inflight Maintenance (IFM) Task and Support Requirements Analysis Specification. This document will provide definitive guidelines for future spacecraft and payload contractors as to the analytical methods to be used in determining operational IFM crew requirements and in designing and planning for IFM tasks. In addition requirements for standard documentation concepts, easily adaptable to data processing methods, of these IFM analyses are specified.

The recommended General Specification, Inflight Maintenance Task and Support Requirements Analysis that was developed by General Electric Houston Operations to satisfy the Phase IIIA contractual requirements of the statement-of-work paragraphs 3.6 and 3.11 is included as Appendix C of this report. This specification also is presently in review by JSC technical monitors and center personnel.

This specification was developed to define methods of analyzing and predicting the operational crew requirements associated with spacecraft contingency maintenance and with the on-orbit servicing of payloads such that IFM related support equipment and procedures can be determined and related design and loose equipment provisions be incorporated in spacecraft and payload designs.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The Phase IIIA Crew Interface Specification Development Study has provided the NASA with drafts for additional crew interface specifications. These specifications are:

- General Specification, Inflight Maintenance Management Requirements
- General Specification, Task and Support Equipment Requirements Analysis

These specifications have been submitted to the technical monitors at the NASA-Johnson Space Center and are in the process of review by Center personnel.

During the Phase IIIA study more definitive data on program management and technical requirements for the Space Shuttle program became available and was reviewed as background material for the two specifications products of this study phase.

It is apparent that the emphasis of the Space Shuttle program and in future programs will be upon greater economies in both manned and unmanned space operations. Greater dependence on crew inflight maintenance activities as on-orbit operational concepts that can increase mission reliabilities while reducing equipment reliability and test requirements is projected. The risk off-set by on-orbit checkout prior to deployment, servicing and refurbishment of payloads will permit cost reductions in their design and testing.

During Phase III additional empirical data on the value and planning requirements for inflight maintenance was obtained from the Skylab mission experiences. Even though many of these Skylab contingency inflight maintenance activities were planned during the mission, they were planned well by many program and ground support personnel. It is anticipated that future space program IFM activities will continue to be crew tasks that are designed for and planned well.

Although scheduled IFM tasks are operationally included as integral with normal mission plans and timelines, they are unique from normal systems operations tasks in that the IFM tasks are identified through different analytical processes and they require provisioning for additional on-board equipment to support the tasks, such as tools, spares, etc.

These additional IFM requirements thus require special management engineering and provisioning processes. These processes need continuity and focusing of program management. As a result a recommendation from this report is that there be a designated responsibility for the Inflight Maintenance program. The IFM organization must also be in a position to interface with the Shuttle Program Maintainability and Maintenance Organization as well as to be closely associated with the organizations responsible for crew procedures development and crew training.

Another new requirement of the Space Shuttle program will be the fact that responsibility for payloads development and operations will not be a unique NASA function but will also be the responsibility of Department of Defense, foreign country and commercial organizations. In these cases where direction and management of payloads development do not fall entirely within NASA's surveillance, it appears that definitive operational IFM guidelines and related design criteria should be provided by the NASA to these organizations so that they can benefit from the unique operational experience that has been obtained in previous manned spaceflights to date. Another specific recommendation of the Phase IIIA study has been to include a process function and documentation requirement (3.6 and 4.1 on the IFM Process Flow Diagram - Figure 1, Appendix A.) for development of Inflight Maintenance Design Criteria for Spacecraft and Payloads Integration.

Other study recommendations for continued development of the format and content of IFM data products to support on-board crew diagnostic and corrective maintenance tasks have been included in a recommended study plan for a Phase IIIB follow-on study.

SC-M-0016

APPENDIX A

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JOHNSON SPACE CENTER

HOUSTON, TEXAS

PROPOSED

GENERAL SPECIFICATION, INFLIGHT MAINTENANCE MANAGEMENT REQUIREMENTS

I

FOREWARD

The spacecraft utilized in Mercury, Gemini and Apollo were designed for relatively short-term missions, and therefore were designed for extremely high reliability and adequate redundancy in order to preclude or limit inflight maintenance operations on the vehicles. Minor servicing and repair tasks were performed on the Apollo Command Modules, but inflight corrective maintenance was not a function that was seriously considered for Apollo.

With the advent of Skylab and the requirement that one unique manned vehicle be operated on orbit for many months, it became obvious that equipment would fail and therefore must be replaced or repaired on orbit. Equipment did in fact fail and was replaced or repaired by the flight crews using tools and spares carried on board as well as special tools and equipment developed on the ground and launched with the crews to enable them to perform unplanned contingency maintenance activities. Inflight maintenance on Skylab, planned on the ground and performed on orbit, saved the Skylab mission.

Future manned programs such as the Shuttle, Shuttle Payloads, Space Station and related serviceable satellites will involve systems and modules that will remain in space for extended periods. These vehicles and modules must from the onset be designed for compatibility of vehicle, serviceable payloads and satellites for effective inflight maintenance capability. This specification has been prepared to enable NASA and its contractors to manage inflight maintenance and meet the needs that future manned programs will generate with respect to this discipline.

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1.0 INTRODUCTION

1.1 PURPOSE. The purpose of this specification is to define the general inflight maintenance management process to be utilized in manned spacecraft programs and to identify the supporting documents and elements necessary for all phases of a program. Through application of this specification, all program functions, reviews, milestones, demonstrations, training, and operations requiring inflight maintenance activities shall be supported with appropriate tools, test equipment, special support equipment, spares, mockups, and procedural and systems data which previous program experience has shown to be necessary for effective operations and training.

1.2 SCOPE. This document establishes the policy, terms, and conditions governing the implementation and execution of the inflight maintenance management process and is applicable to all manned spacecraft programs including earth orbital shuttles, space stations, space tugs, interplanetary spacecraft and all satellites or payloads on which maintenance will be performed by crewmen in space. Specifically, this document provides:

a. A description of an inflight maintenance management process for NASA manned spacecraft and payloads programs which delineates in a time-phased manner, the management and engineering functions and related outputs of NASA and NASA contractor organizations participating in this process.

b. Identification of the technical and management interfaces between this inflight maintenance process and the NASA Spacecraft Maintainability and Maintenance Engineering processes supporting ground operations of Shuttle orbiter vehicles and payloads.

c. Identification of documentation and data product requirements from analytical and engineering process elements to support designing of spacecraft and payloads for IFM and the procedural planning and equipment provisioning for maintenance tasks during inflight operations.

1.3 APPLICABLE DOCUMENTS. The following documents, of the issue in effect on the date of invitations for bids or procurement, form a part of this specification to the extent specified herein.

1.3.1 NASA Specifications

NMI 8020.18A - Space Shuttle Program Management

1.3.1 NASA Specifications(continued)

JSC - 07700 - Volume XI - Space Shuttle Program
Crew Operations, Level II Program Definition and Requirements

MSC - 07700 - Volume XII - Space Shuttle Program
Integrated Logistics Requirements, Level II Program Requirements

1.4 DEFINITIONS. For the purpose of this specification, the following definitions shall apply:

a. Accessibility - a measure of the relative ease of admission to the various areas of an item.

b. Availability - a measure of the degree to which an item is in the operable and committable state when its use is called for at an unknown (random) point in time.

c. Checkout - tests or observations of an item to determine its conditions or status.

d. Demonstration - the testing of an equipment item or system to prove that specified quantitative and qualitative maintainability characteristics are inherent in the design of the equipment or system.

e. Dependability - a measure of the item operating condition at one or more points during the mission, including the effects of Reliability, Maintainability and Survivability, given the item condition(s) at the start of the mission. It may be stated as the probability that an item will (a) enter or occupy any one of its required operational modes during a specified mission, (b) perform the functions associated with those operational modes.

f. Design criteria - narrative or quantitative statements that define the required functional and physical characteristics of an equipment item or system. (e.g., "self-test provisions shall be provided to verify the proper function of each plug-in assembly.")

g. Design liaison - the monitoring of design progress and the review of engineering data and equipment to assess maintainability characteristics of the design, and the interfacing activity with the design organization in order to influence the ultimate equipment-support characteristics.

h. Design review - the evaluation of drawings, sketches, mock-ups, assemblies, and other items which describe the equipment/system design. This evaluation is performed to assess potential and existing problems related to (1) the manufacture of the equipment, (2) its functional capability, and (3) the support of the equipment or system. The design review is normally conducted in a formal meeting which is attended by representatives from the various areas of interest (e.g., human engineering, maintainability, reliability, systems and design engineering, manufacturing engineering, etc.). As a result of this joint meeting, major trade-off decisions are made, and direction is issued which reflects these conclusions.

i. Failure - the inability of an item to perform within previously specified limits.

j. Failure analysis - the logical, systematic examination of an item or its diagram(s) to identify and analyze the probability, causes, and consequences of potential and real failures.

k. Human engineering - the area of human factors which applies scientific knowledge to the design of items to achieve effective man-machine integration and itilization.

l. Human factors - a body of scientific facts about human characteristics. The term covers all biomedical and psychosocial considerations: it includes, but is not limited to, principles and applications in the areas of human engineering, personnel selection, training, life support, job performance aids, and human performance evaluation.

m. Item - used to denote any level of hardware assembly; i.e., system, segment of a system, subsystem, equipment component, part, etc.

n. Inflight Replaceable Unit (IFRU) - an item which, when unserviceable, can be restored to an operational condition through replacement by the flight crew during flight or space operations.

o. Life support - that area of human factors which applies scientific knowledge to items which require special attention or provisions for health promotion, biomedical aspects of safety, protection, sustenance, escape, survival, and recovery of personnel.

p. <u>Maintainability</u> - a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

q. <u>Maintainability analysis</u> - the sequential development and review of data--concurrent with, or preceding design development--to aid in describing the optimum design characteristics of the equipment or system. The elements considered in the review are (1) quantitative requirements, (2) support resources, (3) cost, (4) operational objectives, and (5) safety. The results of the review are translated into criteria which are applied to the design process.

r. <u>Maintainability engineering</u> - an organization that is associated with the functions of maintenance engineering, maintainability-design liaison, systems analysis, design services, support documentation, systems planning, safety engineering, and systems integration and test.

s. <u>Maintenance</u> - all actions necessary for retaining an item in or restoring it to a specified condition.

t. <u>Maintenance analysis</u> - the review of engineering drawings and equipment--concurrent with, or following design development--to validate the maintainability-analysis data. This is a formal review with the findings recorded in a prescribed format. The scope of this review is identical to that of the maintainability analysis.

u. <u>Maintenance concept</u> - a narrative statement or illustration that defines the theoretical means of maintaining an equipment item or system. The statement or illustration relates the tasks that should be performed, the test equipment and tools that should be used in maintenance of the items, and the skill levels of the maintenance personnel that perform the identified tasks.

v. <u>Maintenance engineering</u> - an organization or function that is usually associated with the tasks of maintenance analysis, maintenance studies, maintenance-policy generation, support planning, and maintenance-procedures development. These tasks are usually included in the functions performed by the maintainability organization.

w. Maintenance, inflight - all scheduled and unscheduled maintenance actions performed by the crew while in-orbit, translunar or transplanetary flight.

x. Maintenance plan - a narrative statement or illustration that defines the practical means of maintaining an equipment item or system. This is an extension of the maintenance concept with due consideration for the inherent characteristics of the equipment/system design and other constraints or limitations.

y. Maintenance, scheduled - the actions performed on a time scheduled basis that attempts to retain an item in a specified condition by providing systematic inspection, detection and prevention of incipient failure.

z. Maintenance, unscheduled - the actions performed, as a result of failure, to restore an item to a specified condition.

aa. Mean Time Between Failures (MTBF) - the mean value of the operating periods between all failures of an item or particular equipment over an observed period of time.

bb. Redundancy - the existence of more than one means for accomplishing a given function. Each means of accomplishing the function need not necessarily be identical.

cc. Reliability - the probability that an item will perform its intended function for a specified interval under stated conditions.

dd. Servicing - the replenishment of consumables needed to keep an item in operating condition, but not including any other preventive maintenance or any corrective maintenance.

2.0 RESPONSIBILITIES

The National Aeronautics and Space Administration, Lyndon B. Johnson Space Center (NASA/JSC) shall insure compliance to this specification by contractors or designated government organizations responsible for implementation of the inflight maintenance management process defined herein for manned spacecraft programs and associated payloads. As a minimum, this shall include organizations responsible for:

a. Management of the inflight maintenance design liaison activities during program development

b. Conduct and documentation of inflight maintenance task and support equipment requirements analyses

c. Documentation of inflight maintenance support equipment requirements (e.g., tools, spares, special test equipment, etc.)

d. Development and verification of crew inflight maintenance procedures and supporting systems data

e. Crew training for inflight maintenance tasks

Requests for deviations, additions, or deletions to this specification shall be forwarded to the applicable NASA/JSC spacecraft program office.

3.0 DESCRIPTION OF THE NASA INFLIGHT MAINTENANCE MANAGEMENT PROCESS

3.1 GENERAL DESCRIPTION. (See Figure 1). Inflight maintenance management for a manned spacecraft program is a process which spans all major phases of the system development cycle. In order to describe this process, it is necessary to relate the functional interaction of the following elements:

a. Program activities and milestones which involve review of inflight maintenance concepts, plans, analyses, demonstrations, equipment, documentation, and training

b. NASA and contractor Maintainability and Inflight Maintenance organizations and their respective responsibilities

c. IFM analyses and documentation products of IFM tasks and support equipment requirements

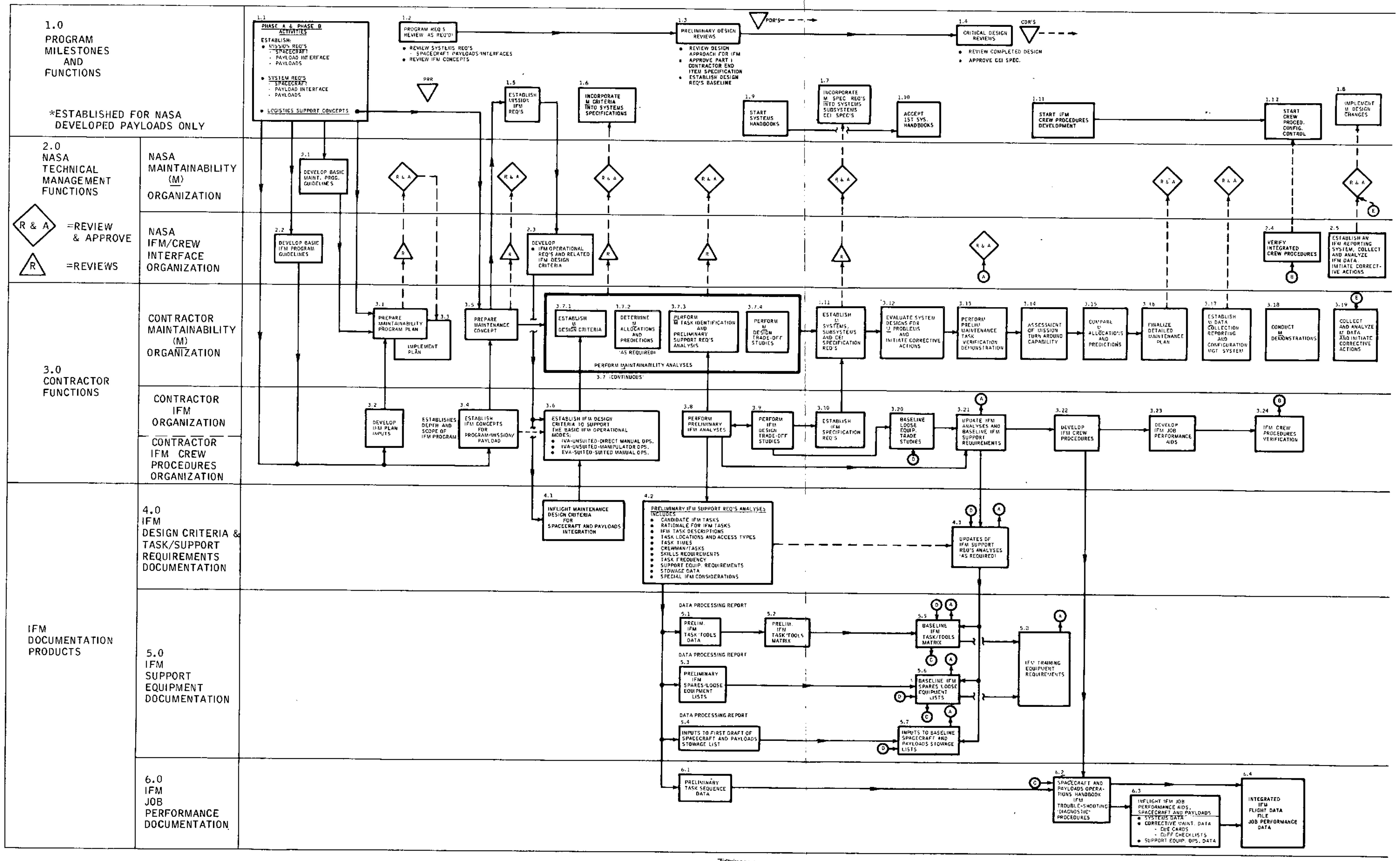
d. IFM task/equipment lists for crew procedures development and IFM support equipment provisioning

Figure 1 is a flow diagram overview of the inflight maintenance management process which illustrates the process elements of inflight maintenance and their interaction with typical spacecraft and payloads program milestones and ground Maintainability program process elements through analysis, definition, design, development and training operations. These other program process elements are included in this flow diagram because of the requirement for the inflight maintenance process to be in consonance with the implemented spacecraft ground maintainability program and with design and development program milestones. In Paragraph 3.2 the Maintainability and Maintenance Engineering Program to be utilized to support ground operations of future shuttlecraft and payloads programs is discussed. This section provides background information on the evolution of the programs that are being implemented to support future manned spaceflight ground operations and references source data that describes in detail the functions of these contractor Maintainability process elements.

Paragraphs 3.3-3.6 contain detailed descriptions of the elements that constitute the inflight maintenance process functions to be accomplished by NASA and contractor organizations that are assigned these functional responsibilities.

Identification of the documentation requirements that support the inflight maintenance process is provided in Section 4.0.

FIGURE 1. NASA INFLIGHT MAINTENANCE MANAGEMENT PROCESS



3.2 MAINTAINABILITY AND MAINTENANCE ENGINEERING PROGRAM (GROUND OPERATIONS). With the Space Shuttle program has come a new operational concept of "reuseability" of spacecraft and payloads. Implementation of this concept involves major revisions of the ground operations functions to include quick turnaround of the spacecraft and payloads. Ground Operations for previous space missions involved only the pre-launch checkout, preparation and launch of spacecraft. Launches were relatively widely spaced in time and since new vehicles and other facilities were used for the next launch many checkout operations of spacecraft could be accomplished in parallel. However, with the concept of "reuseability" and launch schedules of greater frequencies, serial launches of spacecraft can be expected with turnaround operations of 7-10 days. Spacecraft ground and maintenance operations will therefore more nearly approach the aircraft maintenance operations of the Department of Defense and commercial airlines.

After World War II, as aircraft and missile performance increased and systems became more complex, the costs associated with the operations and maintenance of forces and fleets of aircraft showed even greater increase than the equipment costs. This brought about great concern within the military to reduce maintenance costs. Formal analytical and technical activities were specified and documentation required of contractors to assure that designing and planning for maintenance would be done. As a result, significant efficiencies in defense and airline maintenance operations and costs have been realized. NASA, in an effort to reduce program costs and to benefit from the related experience of these other government and commercial organizations, has used these proven maintenance program methods and techniques as a basis for the Maintainability and Maintenance Engineering processes to be utilized in the NASA Integrated Logistics Programs for future shuttlecraft and payloads.

Those process elements identified under the Contractor Maintainability (M) organization functions (3.0) in the NASA Inflight Maintenance Management Process flow diagram (Figure 1) and the related NASA management and review functions (2.0) constitute the major technical requirements of the NASA Maintainability Program supporting ground operations. These technical process requirements are specified in detail in the Space Shuttle program Level II requirements document, "MSC 07700, Volume XII, Integrated Logistics Requirements, Level II Program Requirements." Since these Maintainability Program process elements are well defined and may be referenced in this Level II document and since the primary concern of this IFM specification is with the support of the inflight maintenance operations, no detailed discussion of these basic Maintainability Program process elements is included in this document.

3.3 NASA PROGRAM MILESTONES AND IFM RELATED PROGRAM MANAGEMENT FUNCTIONS (SEE ROW 1.0, FIGURE 1).

Selected program management functions and milestones that establish the basic NASA space vehicle or payload developmental program structure with which the inflight maintenance management process must interface are presented in Row 1.0 of Figure 1. Included are the early program planning (1.1) and program requirements and design reviews (1.2, 1.3, and 1.4) where IFM concepts are reviewed and formalized into Mission IFM Requirements (1.5). Maintainability criteria, developed during early planning and design phases, are incorporated as a management function into program specifications (1.6 and 1.7) as directions for systems designers and operations planners. Software development milestones (1.9, 1.10, 1.11 and 1.12) define IFM related program elements that support crew training and crew procedures development activities. From test and operations data (1.8) corrective actions and requirements for design changes to insure ground and flight safety as well as efficient maintenance operatios will be implemented as a program management function.

Detailed discussions of the above milestones may be obtained from program management documents pertinent to the specific development program such as Space Shuttle Management documents:

- NMI 8020.18A
- JSC - 07700 - Volume XI
- MSC - 07700 - Volume XII

Other management functions related to implementation of Inflight Maintenance and Maintainability criteria will be discussed in conjunction with the NASA technical management functions in the following paragraph.

3.4 NASA MAINTAINABILITY ORGANIZATION FUNCTIONS (SEE ROW 2, FIGURE 1).

NASA management functions have been included in the Inflight Maintenance Management Process flow diagram (Figure 1) to provide visibility as to both technical and management interfaces required of the IFM process. Those functions and responsibilities of the Maintainability organization are included as a part of Row 2, Figure 1. This organization will be responsible for the technical and administrative management of the Maintainability programs for space vehicle development projects. This responsibility is an integral part of the larger Integrated Logistics management function. (For the Space Shuttle Program, the Integrated Logistics Requirements have been specified in MSC 07700 Volume XII, Level II Program Requirements Document.) It is a specified logistics responsibility of Shuttle project managers to assure that support requirements analysis is performed in parallel with system and hardware design. This analysis and support planning will define, as a minimum, the ground support equipment, logistics facilities requirements, spare parts, consumables, personnel, training and technical data needed.

From the above basic integrated logistics requirement is derived the maintainability and maintenance engineering functions which are integrated with the design engineering effort to assure that space vehicle systems are designed for maintainability and operations are planned for maintenance.

The NASA maintainability organization functions are specifically to provide program guidelines (2.1, Figure 1) to contractor maintainability organizations and to review and approve the technical maintainability trade-off data and maintenance analytical data developed by this engineering organization and to effect the incorporation of maintainability design criteria into systems and subsystems Contractor End Item (CEI) specifications as directives and maintenance policies to be used by designers and mission planners. In addition the NASA maintainability organization will conduct and coordinate spacecraft and/or payloads design reviews and monitor verification testing and demonstration of adequate maintenance design and operational provisions.

3.5 NASA IFM/CREW INTERFACE ORGANIZATION FUNCTIONS (SEE ROW 2.0, FIGURE 1). The IFM/Crew Interface organization is responsible for the technical management task of assuring the adequate consideration of crew operational performance capabilities and limitations, resulting from the zero-g/free space environment, in the design and planning for space vehicle and payloads systems designs. This is accomplished through the development of IFM program guidelines (2.2) and IFM operational requirements and design criteria (2.3) for contractor personnel and through the technical management of systematic analyses to identify the unique tasks and support requirements for inflight maintenance. In addition, this organization will participate with the NASA Crew Procedures Development organization in the verification of the Integrated Crew IFM procedures (2.4). Subsequently, the IFM/Crew Interface organization will establish a system to collect IFM data from inflight operations and will collect, analyze and initiate corrective actions as is appropriate (2.5).

The IFM/Crew Interface organization will function as an interface organization between the project Maintainability program organization and the flight crew training and operations support functional organization. Specifically, they will review and approve:

a. Contractor developed IFM Design Criteria that is to be incorporated into the Maintainability Program Design criteria data

b. Task and Support Requirements Analysis Data

c. Baseline IFM Support requirements

d. IFM Design Trade-off Studies wherein trade-offs are made between:
   1) Component Reliability
   2) Systems Redundancy

3) Systems Performance Degradation Acceptance

or:

4) Inflight Maintenance

or:

5) Reentry Ground Maintenance and/or Ground Refurbishment, Relaunch and Reployment

e. IFM Training Requirements (Review Only)

f. Operations Handbook IFM Crew Procedures (Review Only)

3.6 CONTRACTOR MAINTAINABILITY ORGANIZATION(SEE 3.0, FIGURE 1). Each NASA Project Manager shall ensure the establishment and maintenance of an effective maintainability effort integrated with the design engineering activity to assure consideration of operational maintenance requirements in systems design. The contractor Maintainability organization function will be to define and implement a Maintainability Program Plan (3.1) that establishes the technical and management elements to be utilized in the conduct of the program. This plan will serve as a basis for monitoring and evaluating the program which shall include as a minimum the following elements:

1) Establish Maintainability Design Criteria.
2) Perform Maintainability Analysis to establish basic quantitative maintainability parameters such as mean-time-between repair; to budget these parameters to system/subsystem/ components; to perform maintenance tasks and support requirements analyses.
3) Prepare inputs to the Detailed Maintenance Concept and Detailed Maintenance Plan. Areas of particular interest are assessments of the depth and frequency of maintenance requirements.
4) Incorporate and enforce maintainability requirements in subcontractor and vendor contract specifications.
5) Participate in design reviews and evaluations of systems designs. Identify maintainability problems and initiate corrective design actions.

6) Perform maintainability design trade-off studies.
7) Predict maintainability parameters values, quantitative predictions and budgeted allocations to systems, sub-systems, etc. will be maintained and subsequently verified during program maintainability test and verification activities.
8) Establish a Maintainability Configuration Control System for data collection analysis recommendations and follow-up. A formal approval/corrective action tracking system will be maintained.
9) Conduct maintainability verification and demonstration activities to verify the achievement of the design maintainability requirements.

The above noted process elements and responsibilities of the contractor maintainability organization are defined in more detail in "MSC 07700, Volume XII, Space Shuttle Program Integrated Logistics Requirements Level II Program Requirements."

3.7 CONTRACTOR INFLIGHT MAINTENANCE (IFM) ORGANIZATION FUNCTIONS (SEE 3.0 FIGURE 1). The contractor IFM organization, like the NASA IFM/Crew Interface organization is an interface group providing liaison and coordination between crew operations, crew procedures and training areas and the basic project maintainability program. The IFM organization must maintain an awareness of all aspects of the maintainability program as well as to develop and maintain knowledge of operational problems associated with performing of maintenance tasks in zero-g and free space environments.

The process elements required to implement these functions include:

a) Development and preparation of Inflight Maintenance inputs to the basic Maintainability Program Plan (3.2). Since spacecraft and payloads development programs will generally utilize the basic guidelines of not designing systems for inflight maintenance unless other design alternatives have been exhausted, early program Maintainability Plans may not consider IFM requirements. However, spaceflight operational experience has shown that some degree of IFM capability is normally provided in the way of basic tools, spares, etc. It is the responsibility of the IFM organization function to assure that those items of IFM included on-board have been analyzed and documented as per the requirements of this specification.

b) Development and preparation of IFM inputs to the basic Maintenance Concept (3.4). These inputs will establish the depth and the scope of the contractor IFM program and the basic methods of interfacing with payload IFM activities.

c) Establishment of IFM Design Criteria(3.6). The contractor shall be required to develop specific programs related IFM Design Criteria data that will later be incorporated with other Maintainability criteria and integrated into Systems Specifications. These criteria data for IFM will be developed from historical spaceflight operational data and related design criteria provided by the Inflight Maintenance and Design Criteria for Spacecraft and Payloads Integration Document(4.1) that is developed and maintained by the NASA IFM/Crew Interface Organization.

d) Performance of an Inflight Maintenance Task and Support Requirements Analyses (3.8). A major task responsibility of the contractor IFM organization is to conduct and document the IFM task and support requirements analyses. The required analytical methods and format and contents of related documentation of this analyses is specified in detail in the NASA JSC Specification ____________ (General Specification, IFM Task/ Support Requirements Analysis). This analysis and documentation provides the baseline reference data for later development and definition of IFM loose equipment requirements and crew IFM procedures. The task and support requirements data is developed on standard data processing formats that allow subsequent equipment listings and correlation data on task/tools and equipment to be generated for equipment provisioning and logistics purposes. Preliminary IFM crew procedures data may also be developed from these data formats.

The IFM Task and Support Requirements Analysis provides the basic operational technical background for subsequent special IFM design trade-off studies (3.9) and the definition of IFM specification data (3.10) that is subsequently to be incorporated into the Contractor End Item Specifications.

e. Conduct of Baseline Loose Equipment Trade-Off Studies(3.20). After listings of IFM loose equipment are developed from the Task and Support Requirements Analysis data, studies will be conducted by the contractor IFM organization to optimize, as is required, the tools, spares and other IFM support equipment. Redundancies of equipment requirements will be eliminated and baseline lists of IFM loose equipment requirements (5.5 and 5.6) developed. Input data to the baseline spacecraft and payloads stowage lists will also be provided by these baseline IFM equipment studies.

f. Updates of IFM Analyses and Baseline IFM Support Requirements (3.21). These analyses and baseline data shall be maintained current by the contractor IFM organization. This involves elimination of some candidate IFM items data and incorporation of data for IFM items that have been added to the IFM capability with subsequent modifications being made to the baseline IFM loose equipment data.

g. Development of Spacecraft and Payloads Inflight Maintenance Crew Procedures Data (3.22). The contractor IFM organization will prepare the preliminary Inflight Maintenance Systems Procedures from the data base of the Task and Support Requirements analyses. These procedures will be mission phase independent and will be validated by the contractor (3.24) through analyses and demonstration on mock-ups. These procedures then serve as a basis for the development of the Crew Integrated Procedures that are usually Mission Phase Dependent. The scheduled IFM procedural data will be integrated with the normal/backup procedures and will be mission time-sequenced while unscheduled IFM tasks may be integrated with malfunction procedures or contingency procedures as is appropriate. These procedures will be reviewed and validated by the NASA IFM/Crew Interface functional organization with the assistance of contractor crew procedures personnel. Subsequently, the IFM procedures are integrated as check list data into the on-board flight data file. In addition, the IFM procedures must be integrated with the flight planning technique being utilized on the specific project or program.

g. (continued)
The crew procedures development processes are discussed in more definitive detail in the Space Shuttle Program document "JSC 07700, Volume XI, Crew Operations Level II Program Definition and Requirements."

h. Development of IFM Job Performance Aids (3.23). Of all the types of on-board crew procedures data used in the Flight Data File, the IFM crew procedures are unique in requiring more extensive graphic and pictoral support data integrated with the procedures than is required for all other procedures types. Such procedural data is considered a job performance aid. Such aids for IFM are required because of the safety implications of maintenance tasks in space. Namely the crew needs accurate pictoral or detailed graphics data to compare with the actual equipment and determine the accurate location and identification of the part, wire or lines that must be changed or modified during the IFM task.

The contractor should develop concepts and ideas for IFM performance aids that can assist the NASA-JSC in development of the Flight Data File and in providing sufficient procedural aids to assure safety of flight.

4.0 INFLIGHT MAINTENANCE DOCUMENTATION PRODUCTS REQUIREMENTS (SEE 4.0, FIGURE 1). The data products that are required to document required IFM analytical tasks and to support program design, logistics, and crew operations activities are included in Rows 4.0, 5.0 and 6.0 of Figure 1. These IFM documentation products are included in the Inflight Maintenance Management Process diagram to provide visibility as to the documentation products resulting from IFM process functions and, where appropriate, to identify those documents where standard format and content requirements should be specified.

4.1 IFM DESIGN CRITERIA AND TASK/SUPPORT REQUIREMENTS DOCUMENTATION (SEE ROW 4.0, FIGURE 1). The IFM documentation products that are developed during the design phases of space vehicle or payloads developmental programs are identified in Row 4.0 of Figure 1. These IFM data products support the development of acceptable maintainability of space vehicle and payload systems and assist in defining loose equipment requirements to support IFM activities. There are two basic design phase IFM documentation product requirements which are:

a) Inflight Maintenance Design Criteria for Spacecraft and Payloads Integration (4.1)

The requirement for this document stems from the relatively little manned spaceflight experience that has been accrued outside of the NASA programs. In addition, experience with inflight maintenance tasks, even in NASA programs, was meager until the Skylab missions. However, with the anomalies of this program, a major amount of operational experience has been gained in the inflight repair of major spacecraft systems problems as well as many minor experiments and other loose equipment problems.

The purpose of the IFM Design Criteria document is to translate the NASA flight operations experience into practical guidelines and design criteria that can be used by spacecraft and payloads development contractors and organizations in the design of space systems and in the planning of spaceflight operations.

Since the historical data, that is the basis for such a document, exists in NASA data bases and film files, the development and maintenance of the IFM Design Criteria for Spacecraft and Payloads Integration document shall be the responsibility of the organization assigned the IFM/Crew Interface functional task. The document shall include but not be limited to:

(1) Definitions of spacecraft and payloads systems safety requirements for IFM operations under specified environmental conditions (e.g., electrical power control and electrical power disconnects, fluid flow management, safety provision for closure of critical access covers and doors, etc.).

(2) Life support considerations and requirements, definitions of IFM related EVA equipment requirements and basic timeline budgets associated with EVA Preparations, egress translation to worksite, worksite stabilization, performance of corrective maintenance, translation and ingress, and EVA closeout.

(3) Systems design provisions for IFM component failure identification, accessibility, bypass and isolation, and replaceability.

(4) Design guidelines and criteria for mobility and translation aids within and external to the space vehicle and payloads under both pressurized and suited unpressurized conditions. These guidelines should include but not be limited to IVA and EVA aids for suited and unsuited operations such as handholds, rails, etc. as well as hand-held or body-mounted maneuvering units.

(5) Design guidelines and criteria for zero-g restraints and tethers for safety and for stabilization at worksites to allow applications of forces to accomplish maintenance tasks.

(6) Design guidelines and criteria for labelling and identification of components and spares for IFM operations.

(7) Design guidelines and criteria for equipment containment devices to aid in handling and management of tools and parts during maintenance tasks.

(8) Definitions of the operational capabilities and performance characteristics of on-board manipulator provisions including forces, movement rates and end-effector configurations and capabilities.

b) Inflight Maintenance Task and Support Requirements Analysis Documentation (4.2, Figure 1).
This is the basic documentation requirement of the inflight maintenance and support requirement analyses conducted to support program design phase activities. The format and contents of this documentation shall be prepared in accordance with the provisions of the General Specification, Inflight Maintenance Task and Support Requirement Analysis, TBD . This specification defines methods and the standard format and contents to be used in documenting the analytical examination of IFM tasks and the assessment of equipment and/or software requirements essential to performance of these tasks.

4.2 INFLIGHT SUPPORT EQUIPMENT DOCUMENTATION (SEE 5.0, FIGURE 1). One of the unique characteristics of inflight maintenance is the requirement for additional on-board equipment other than the existing in-place systems hardware. This equipment includes mainly the tools that enable the crew to perform the maintenance and the spares to replace the faulty items. However, other items may also be necessary to support the IFM tasks such as safety tethers for zero-g, lights to illuminate task area, etc. The need for this additional equipment on-board can have significant impacts on spacecraft and payloads design; on procurement and provisioning of on-board loose equipment; on stowage and preparations of the vehicle and payloads for flight; and on house-keeping and loose equipments management by the crew in flight.

These program impacts that result from IFM activity must be resolved concurrently with the normal systems design, test and evaluation so that the IFM equipment and supporting IFM procedures are available at time of flight and can be stowed on-board the flight vehicle.

The necessity to support the above concurrency requirements is the basic rationale for the development of the IFM Task and Support Requirement Analysis methods and documentation. Through this identification of IFM tasks and their related support equipment early in program development, design requirements, such as providing accessibility to the IFRU and provisionings for stowage of tools and spares, can be built into the design. This reduces the expensive design changes and systems reconfiguration that must be incorporated after the basic hardware has been built.

The Task and Support Requirements Analysis also serves as a basis for the early identification of IFM support equipment that must be included with other on-board loose equipment. The procurement of this equipment must be initiated through the Integrated Logistics Program activities. To support such activities, special documentation is required relative to Inflight Maintenance.

Utilizing the Task and Support Requirements Analysis data base, the contractor will provide various reports listing the IFM support equipment requirements for all candidate IFM items. The specific format and content requirements of these reports will be developed by the contractor and approved by the NASA IFM/Crew Interface Organization function and the NASA Program Integrated Logistics function. These logistics reports shall include but not be limited to:

a. Preliminary and baseline correlated lists of tasks and tool requirements (5.1, 5.2, 5.5)

b. Preliminary and baseline correlated lists of tasks and spares and other IFM loose equipment requirements (5.3, 5.6)

c. Preliminary and baseline lists of IFM equipment in formats suitable for stowage list development usages (5.4, 5.7)

The IFM Task and Support Requirements Analysis data base also can be used as a basis for other data products that will support flight crew procedures development and crew training functions. The contractor will provide such reports, the content and formats of which must be approved by the NASA IFM/Crew Interface organization function. The delivery of these reports will be in consonance with other program functions and must be timely for support of crew procedures and training development functions. These reports shall include but not be limited to:

a. Correlated lists of tasks/skill requirements

b. Lists of specific crew IFM training equipment requirements

4.3 INFLIGHT MAINTENANCE JOB PERFORMANCE DOCUMENTATION (SEE 6.0, FIGURE 1).

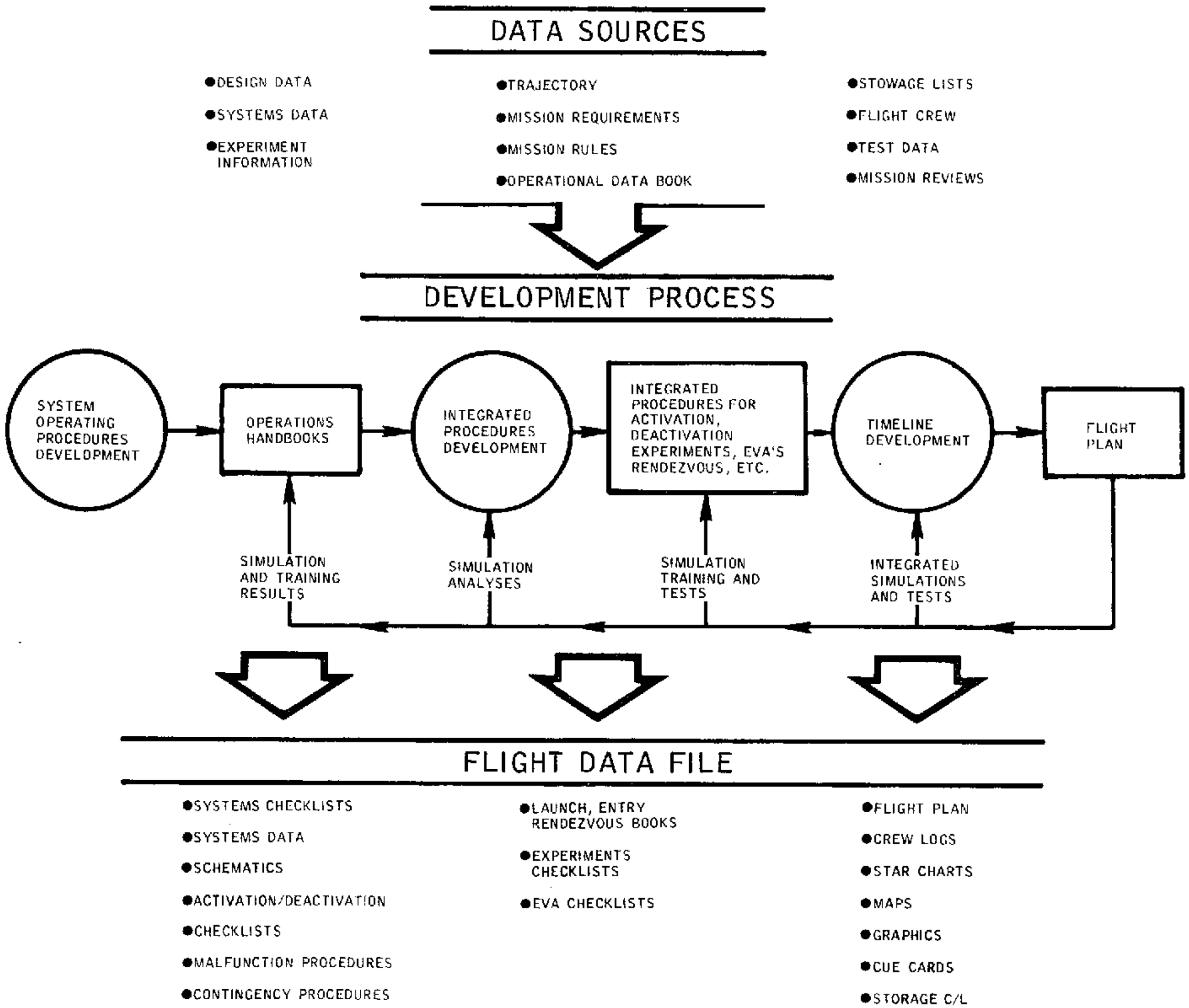
The IFM Task and Support Requirements Analysis data base also provides the basis for other data products that will support the development of crew procedures for Inflight Maintenance training and inflight operations. From the data base, the contractor will generate reports providing task description and task sequence data for all candidate IFM items (6.1). This data will be correlated with Flight Planning Activity element data and will include any IFM alert information or special IFM problem data.

This Task Description/Task Sequence data will be provided by the contractor IFM organization functions as support data for the development of the contractor procedural inputs (Systems Operating Procedures) to the NASA Spacecraft and/or Payloads Operations Handbooks (6.2) and the Crew Procedures development process. This NASA-JSC process is presented in

Figure 2. This figure also contains the data sources that support the process and the basic data products of the flight data file. These products include procedural checklists, systems and graphics data that serve as real-time mission job performance aids for the crew. For inflight maintenance tasks, special job performance aids may be required to provide the crew with accurate pictoral data integrated with the procedural checklists to support operational safety considerations as well as basic data for training and real-time mission operations.

The contractor IFM organization will provide data concepts for special job performance aids to support the specific candidate IFM items. Where appropriate, the NASA Crew Procedures Development organization will utilize these concepts in preparation of integrated IFM job performance aids (6.3) that will include procedural, systems and pictoral data of worksites and equipment identification. These aids will be prepared for inclusion into the Flight Data File (6.4) after the IFM procedures are verified and approved by contractor and NASA IFM organizations, flight crew and crew procedural development organizations.

FIGURE 2. CREW PROCEDURES DEVELOPMENT PROCESS



APPENDIX B

INFLIGHT MAINTENANCE OPERATIONAL FUNCTIONS ANALYSIS

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FIGURE 2. OPERATIONAL FUNCTIONAL ANALYSIS OF THE BASIC INFLIGHT CORRECTIVE MAINTENANCE TASKS

TYPE OF IFM CORRECTIVE MAINTENANCE	PREPARATION	EGRESS AND INGRESS	TRANSLATION	WORKSITE STABILIZATION	ADDITIONAL TROUBLESHOOTING AND DISASSEMBLY ("OPEN-UP")	CORRECTIVE MAINTENANCE CATEGORY I - REPAIR IN PLACE II - REMOVE-REPLACE-REPAIR III - REMOVE-REPLACE-DISCARD IV - REMOVE-REPAIR-REPLACE	VERIFICATION CHECK-OUT AND REASSEMBLY ("CLOSE-OUT")	RETURN TO OPERATIONAL STATUS
IFM TYPE IP-1 • IVA • PRESSURIZED (SHIRTSLEEVE) • DIRECT MANUAL OPS. • IN MOTHER VEHICLE (M.V.) OR ATTACHED PAYLOAD (PRESS.)	• OBTAIN REQUIRED SUPPORT ITEMS: - TOOLS - SPARES - EQUIPMENT CONTAINMENT DEVICES - SPECIAL TEST EQUIPMENT - TRANSLATION AND WORKSITE STAB. AIDS, IF REQUIRED - PROCEDURES - SYSTEMS DATA, IF REQUIRED		• MOVEMENT THROUGHOUT VEHICLE AND/OR PAYLOAD USING MOBILITY AIDS PROVIDED IN VEHICLE-PAYLOAD PRESSURIZED CREW ACCESSIBLE AREAS	• IF ZERO "G", STABILIZE BODY WITH RESPECT TO WORKSITE SO THAT REQUIRED ROTATIONAL, PUSH-PULL, CUTTING, IMPACT, AND OTHER TYPE TASKS CAN BE ACCOMPLISHED	• ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASKS (CATEGORIES I, II, III OR IV) AS DEFINED IN IFM PROCEDURES	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES (INCLUDING CHECKS FOR ANY LOOSE PARTS IN AREA. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE IPM-2 • IVA • PRESSURIZED(SHIRTSLEEVE) • MOTHER VEH. MANIP. OPS. • FROM M.V. CONTROL STATION • ON MOTHER VEHICLE OR ATTACHED PAYLOAD	• OBTAIN AND INSTALL, IN AIRLOCK FOR MANIPULATOR ACCESSIBILITY, SPARES AND SPECIAL TOOLS, IF REQUIRED FOR IFM • PREPARE AIRLOCK FOR MANIPULATOR ACCESS "AND/OR" DETERMINE IF REQ'D TOOLS, SPARES AND SPECIAL EQUIPMENT ARE STOWED IN EXTERNAL COMPARTMENT ACCESSIBLE TO AND USABLE BY MANIPULATOR → OBTAIN: • PROCEDURES - MANIP. OPS. - IFM • SYSTEMS DATA, AS REQUIRED → • MAN MANIPULATOR STATION • "OPEN" COMPARTMENT DOORS FOR MANIPULATOR AND WORKSITE OPS.				• MAKE VISUAL INSPECTION OF WORKSITE TO DETERMINE IF INITIAL FAULT ISOLATION WAS CORRECT. IF NOT, COORDINATE FURTHER TROUBLE-SHOOTING WITH FLIGHT AND GROUND CONTROL → • OBTAIN SPARES, TOOLS AND SPECIAL EQUIP. FROM AIRLOCK OR STOWAGE LOCATION IN EXTERNAL COMPARTMENT, USING MANIPULATOR AS REQ'D BY PROCEDURES → • ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT. I - MAY INVOLVE AIRLOCK OPS FOR SPARES AND TOOLS CAT. II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES (INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• STOW MANIPULATOR • SECURE AIRLOCK IF REQUIRED • CLOSE COMPARTMENT DOORS → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE IPM-3 • IVA • PRESSURIZED(SHIRTSLEEVE) • MOTHER VEH. MANIP. OPS. • FROM M.V. CONTROL STATION • ON REMOTE VEHICLE (RV)	• OBTAIN AND INSTALL, IN AIRLOCK FOR MANIPULATOR ACCESSIBILITY, SPARES AND SPECIAL TOOLS, IF REQUIRED FOR IFM • PREPARE AIRLOCK FOR MANIPULATOR ACCESS "AND/OR" DETERMINE IF REQ'D TOOLS, SPARES AND SPECIAL EQUIPMENT ARE STOWED IN EXTERNAL COMPARTMENT ACCESSIBLE TO AND USABLE BY MANIPULATOR → OBTAIN: • PROCEDURES - MANIP. OPS. - IFM • SYSTEMS DATA, AS REQUIRED → • MAN MANIPULATOR STATION • "OPEN" COMPARTMENT DOORS FOR MANIPULATOR AND WORKSITE OPS			• STABILIZE REMOTE VEHICLE WITH RESPECT TO MOTHER VEHICLE USING MANIPULATOR	• MAKE VISUAL INSPECTION OF WORKSITE TO DETERMINE IF INITIAL FAULT ISOLATION WAS CORRECT. IF NOT, COORDINATE FURTHER TROUBLE-SHOOTING WITH FLIGHT AND GROUND CONTROL → • OBTAIN SPARES, TOOLS AND SPECIAL EQUIP. FROM AIRLOCK OR STOWAGE LOCATION IN EXTERNAL COMPARTMENT, USING MANIPULATOR AS REQ'D BY PROCEDURES → • ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT I - MAY INVOLVE AIRLOCK OPS FOR SPARES AND TOOLS CAT. II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• DETACH FROM REMOTE VEHICLE → • STOW MANIPULATOR • SECURE AIRLOCK IF REQ'D CLOSE COMPARTMENT DOORS → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE IPM-4 • IVA • PRESSURIZED(SHIRTSLEEVE) • REMOTE TELE. VEHICLE(RTV) MANIPULATOR OPS. • FROM MOTHER VEHICLE CONTROL STATION • ON MOTHER VEHICLE, ATTACHED PAYLOAD OR REMOTE VEHICLE	• PREPARE AND CHECK RTV FOR LAUNCH - OBTAIN TOOLS AND SPARES REQ'D FOR IFM - STOW IN RTV - CHECK OUT RTV COMM. AND SYSTEMS OPS. → OBTAIN • PROCEDURES - RTV OPS. - RTV MANIP. OPS. • SYSTEMS DATA - RTV - WORKSITE VEH. → • MAN RTV CONTROL STATION IN M.V. • LAUNCH RTV FROM M.V. CONTROL STATION USING M.V. MANIPULATOR, IF REQUIRED		• FLY RTV TO WORKSITE UNDER REMOTE CONTROL FROM M.V.	• STABILIZE RTV WITH RESPECT TO WORKSITE VEHICLE	• MAKE VISUAL INSPECTION OF WORKSITE TO DETERMINE IF INITIAL FAULT ISOLATION WAS CORRECT. IF NOT, COORDINATE FURTHER TROUBLE-SHOOTING WITH FLIGHT AND GROUND CONTROL → • OBTAIN SPARES AND TOOLS FROM STOWED LOCATIONS USING RTV MANIPULATOR CONTROLLED FROM MOTHER VEHICLE → • ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT. I - MAY INVOLVE AIRLOCK OPS. FOR SPARES AND TOOLS CAT II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• DETACH FROM WORKSITE VEHICLE → • FLY RTV BACK TO M.V. AND SECURE → • STOW MANIPULATOR • CLOSE COMPARTMENT DOORS → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE IPM-5 • IVA • PRESSURIZED (SHIRTSLEEVE OR UNPRESS. SUITED IN PRESSURIZED RTV • FROM RTV CONTROL STATION • ON MOTHER VEHICLE, ATTACHED PAYLOAD OR REMOTE VEHICLE	• PREPARE AND CHECK RTV FOR LAUNCH - OBTAIN TOOLS AND SPARES REQ'D FOR IFM - STOW IN RTV - CHECK OUT RTV COMM. AND SYSTEMS OPS. → OBTAIN: • PROCEDURES - RTV OPS. - RTV MANIP. OPS. • SYSTEMS DATA - RTV - WORKSITE VEH. → • MAN RTV CONTROL STATION • LAUNCH RTV (USING M.V. MANIPULATOR, IF REQUIRED)		• FLY MANNED RTV TO WORKSITE	• STABILIZE RTV WITH RESPECT TO WORKSITE VEHICLE	• MAKE VISUAL INSPECTION OF WORKSITE TO DETERMINE IF INITIAL FAULT ISOLATION WAS CORRECT. IF NOT, COORDINATE FURTHER TROUBLE-SHOOTING WITH FLIGHT AND GROUND CONTROL → • OBTAIN SPARES AND TOOLS FROM STOWED LOCATIONS USING RTV MANIPULATOR CONTROLLED FROM MOTHER VEHICLE → • ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINTENANCE TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT. I - MAY INVOLVE AIRLOCK OPS. FOR SPARES AND TOOLS CAT. II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• DETACH FROM WORKSITE VEHICLE → • FLY RTV BACK TO M.V. AND SECURE → • STOW MANIPULATOR • CLOSE COMPARTMENT DOORS → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE IU-6 • IVA • UNPRESSURIZED (PRESS. SUITED) • DIRECT MANUAL OPS. • ON MOTHER VEHICLE OR ATTACHED PAYLOADS(UNPRESS.)	• DETERMINE LOCATION (WITH-IN VEHICLE OR IN UNPRESSURIZED COMPT.) OF REQ'D IFM SUPPORT ITEMS. • OBTAIN THOSE ITEMS IN VEH.: - TOOLS - SPARES - EQUIP. CONTAINMENT DEVICES - SPECIAL TEST EQUIP. - TRANSLATION AND WORKSITE STAB. AIDS, IF REQ'D - SAFETY TETHERS - PRESSURE SUIT AND LIFE SUPPORT - PROCEDURES - SYSTEMS DATA, IF REQ'D → • AIRLOCK OPS. - CHECK AIRLOCK PRESS. - DON AND CHECK-OUT PRESSURE SUIT OPS. - PREPARED EQUIP. FOR IFM OPS. - DEPRESS	• EGRESS TO UNPRESSURIZED WORKSITE COMPARTMENT - CHECK FOR CLEARANCE THROUGH AIRLOCK HATCH OF ALL EQUIPMENT ITEMS INCLUDING PRESSURE SUITS AND LIFE SUPPORT EQUIPMENT	• MOVEMENT THROUGHOUT UNPRESS. COMPARTMENT USING MOBILITY AIDS PROVIDED IN COMPARTMENT OR THOSE THAT ARE TRANSPORTED THROUGH AIRLOCK • OBTAIN ITEMS REQ'D TO SUPPORT IFM THAT ARE STOWED IN UNPRESS. COMPT.	• IF ZERO "G", STABILIZE BODY WITH RESPECT TO WORKSITE SO THAT REQUIRED ROTATIONAL, PUSH-PULL, CUTTING, IMPACT, AND OTHER TYPE TASKS CAN BE ACCOMPLISHED	• ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT. I - MAY INVOLVE AIRLOCK OPS. FOR SPARES AND TOOLS CAT. II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• DETACH FROM WORKSITE • RETURN TO AIRLOCK • INGRESS INTO M.V. • DOFF PRESSURE SUIT → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE EU-1 • EVA • UNPRESSURIZED(PRESS. SUITED) • DIRECT MANUAL OPS. • ON MOTHER VEHICLE OR ATTACHED PAYLOAD	• DETERMINE LOCATION (WITH-IN VEHICLE OR IN UNPRESSURIZED COMPT.) OF REQ'D IFM SUPPORT ITEMS. • OBTAIN THOSE ITEMS IN VEH.: - TOOLS - SPARES - EQUIP. CONTAINMENT DEVICES - SPECIAL TEST EQUIP. - TRANSLATION AND WORKSITE STAB. AIDS, IF REQ'D - SAFETY TETHERS - PRESSURE SUIT AND LIFE SUPPORT - PROCEDURES - SYSTEMS DATA, IF REQ'D → • AIRLOCK OPS. - CHECK AIRLOCK PRESS. - DON AND CHECK-OUT PRESSURE SUIT OPS. - PREPARED EQUIP. FOR IFM OPS. - DEPRESS	• EGRESS TO FREE SPACE - CHECK FOR CLEARANCE THROUGH AIRLOCK HATCH OF ALL EQUIPMENT ITEMS INCLUDING PRESSURE SUITS AND LIFE SUPPORT EQUIPMENT	• MOVEMENT TO WORKSITE MAY INVOLVE USE OF VARIOUS TYPES OF TRANSLATION AIDS SUCH AS: - FIXED OR FIXED RETRACTABLE ON VEHICLE - PORTABLE(ATTACHABLE/REMOVABLE) - TELESCOPING RODS - ETC. • OBTAIN ITEMS REQ'D TO SUPPORT IFM THAT ARE STOWED IN UNPRESS. COMPT.	• STABILIZE BODY WITH RESPECT TO WORKSITE SO THAT REQUIRED TORQUING, CUTTING AND OTHER TYPE TASKS CAN BE ACCOMPLISHED	• ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT. I - MAY INVOLVE AIRLOCK OPS. FOR SPARES AND TOOLS CAT. II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• DETACH FROM WORKSITE • RETURN TO AIRLOCK • INGRESS INTO M.V. • DOFF PRESSURE SUIT → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS, AS REQUIRED
IFM TYPE EU-2 • EVA • UNPRESSURIZED (PRESS. SUITED) • DIRECT MANUAL OPS. • ON REMOTE VEHICLE	• DETERMINE LOCATION (WITH-IN VEHICLE OR IN UNPRESSURIZED COMPT.) OF REQ'D IFM SUPPORT ITEMS. • OBTAIN THOSE ITEMS IN VEH.: - TOOLS - SPARES - EQUIP. CONTAINMENT DEVICES - SPECIAL TEST EQUIP. - TRANSLATION AND WORKSITE STAB. AIDS, IF REQ'D - SAFETY TETHERS - PRESSURE SUIT AND LIFE SUPPORT - PROCEDURES (IFM & XLATION DEV. - SYSTEMS DATA, IF REQ'D → • AIRLOCK OPS. - CHECK AIRLOCK PRESS. - DON AND CHECK-OUT PRESSURE SUIT OPS. - PREPARED EQUIP. FOR IFM OPS. - DEPRESS	• EGRESS TO FREE SPACE - CHECK FOR CLEARANCE THROUGH AIRLOCK HATCH OF ALL EQUIPMENT ITEMS INCLUDING PRESSURE SUITS AND LIFE SUPPORT EQUIPMENT	• TRANSLATION TO WORKSITE WILL INVOLVE "BETWEEN VEHICLES" TRANSLATION DEVICES AIDS SUCH AS: - MANEUVERING UNIT (HAND HELD THRUSTER OR MORE COMPLEX DEVICES) - TELESCOPING RODS - PORTABLE (ATTACHABLE REMOVABLE) AIDS - ETC. • OBTAIN ITEMS REQ'D TO SUPPORT IFM THAT ARE STOWED IN UNPRESS. COMPT	• STABILIZE BODY OR UNIT WITH RESPECT TO WORKSITE SO THAT REQUIRED TORQUING, CUTTING AND OTHER TYPE TASKS CAN BE ACCOMPLISHED	• ESTABLISH METHOD OF CONTAINMENT OF PARTS, SPARES, TOOLS, ETC. THROUGHOUT CORRECTIVE MAINT. TASK • REMOVE ACCESS COVERS, PANELS, AND EQUIPMENT ITEMS THAT BLOCK ACCESS TO THE AFFECTED IN FLIGHT REPLACEABLE UNIT (IFRU)	• PERFORM CORRECTIVE MAINTENANCE TASK AS DEFINED IN IFM PROCEDURES FOR THE FOLLOWING: CAT. I - MAY INVOLVE AIRLOCK OPS. FOR SPARES AND TOOLS CAT. II - INVOLVES RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT III - COULD INVOLVE SPACE DUMP OR RETURN OF FAILED COMPONENT THROUGH AIRLOCK CAT. IV - COULD BE REPAIRED AT WORKSITE BUT PROBABLY INVOLVES AIRLOCK OPERATIONS	• REASSEMBLE AND "CLOSE-OUT" WORKSITE AS PER PROCEDURES INCLUDING CHECKS FOR RETURN OF ALL TOOLS AND SPARES THROUGH AIRLOCK OPS. • PERFORM VERIFICATION CHECK-OUT (BEFORE OR AFTER REASSEMBLY, AS REQUIRED)	• DETACH FROM WORKSITE • TRANSLATE TO M.V. • STOW TRANSLATION DEVICE IN COMPARTMENT • INGRESS INTO M.V. • DOFF PRESSURE SUIT → • STOW, DISCARD OR PLAN FOR REPAIR OR EARTH RETURN OF IFM SUPPORT ITEMS AND FAILED COMPONENTS AS REQUIRED

PREPARED BY GENERAL ELECTRIC HOUSTON OPERATIONS IN ACCORDANCE WITH CONTRACT NAS 9-13375 "CREW INTERFACE SPECIFICATION STUDY PROGRAM FOR INFLIGHT MAINTENANCE AND STOWAGE, PHASE III A"

FOLDOUT FRAME FOLDOUT FRAME

FOLDOUT FRAME

INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: IPM-2	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
PREPARATION	1) PROVIDE STOWAGE VOLUME, ACCESSIBILITY AND ENVIRONMENTAL PROTECTION, AS REQUIRED, FOR: a. TOOLS b. SPARES c. EQUIPMENT CONTAINMENT AND STABILIZATION DEVICES d. ASSOCIATED PROCEDURAL AND SYSTEMS DATA 2) MEANS FOR IDENTIFYING, LOCATING VIEWING AND ILLUMINATING, AND PERFORMING IFM OPERATIONS ON WORKSITE ACCESS AND COMPONENTS. (THIS PROBABLY REQUIRES: - MANIPULATOR (FIXED TO MOTHER VEHICLE) - END EFFECTORS FOR MANIPULATOR - REMOTE SENSORS (T.V., PROXIMITY, TACTILE, ETC.) - HARD WIRE COMMAND/CONTROL COMMUNICATIONS	• NO SPECIAL SUPPORT REQUIREMENTS	• HIGH FIDELITY SIMULATOR TO INCLUDE WORKSITE, MANIPULATOR, AIRLOCK (IF REQ'D) AND EQUIPMENT SIMULATION

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: IPM-2	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
PREPARATION (CONTINUED)	2) (CONTINUED) - CONTROL STATION WITH: . GENERAL PURPOSE CONTROLLER (JOYSTICK, SWITCHES, EXOSKELETAL) . DISPLAYS FOR REMOTE IFM VIEWING 3) PROVIDE FOR A MEANS OF PICKUP OR DELIVERY OF REQUIRED IFM SUPPORT ITEMS TO THE MANIPULATOR. THIS MAY REQUIRE: a. SPECIAL AIRLOCK DESIGN THAT CAN BE CONTROLLED REMOTELY AND/OR BY MANIPULATOR b. SPECIAL EVA BY CREWMAN TO DELIVER SUPPORT ITEMS (REFER TO IFM TYPE EV-2) c. STOWAGE IN UNPRESSURIZED COMPARTMENT OF EQUIPMENT		

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: IPM - 2	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
ADDITIONAL TROUBLESHOOTING AND DISASSEMBLY ("OPEN UP")	PROVIDE FOR: 1) INTERFACE COMPATIBILITY OF - MANIPULATOR/END EFFECTOR - EFFECTOR/SPACECRAFT WORKSITE FOR WORK STABILIZATION - END EFFECTOR/TOOL COMPATIBILITY - END EFFECTOR/TOOL/SPACECRAFT WORKSITE ACCESS COMPATIBILITY - END EFFECTOR/TOOL/SPACECRAFT FAILED MODULES AND RETAINERS COMPATIBILITY 2) MANIPULATOR ACCESS TO PLANNED IFM WORKSITE AREAS	PROVIDE FOR: 1) MANIPULATOR, END EFFECTOR, MANIPULATOR CONTROLLER AND DISPLAYS AND FEEDBACK SENSORS FOR FLEXIBILITY OF OPERATIONS TO ALLOW EXTRACTION OF TOOLS AND SPARES FROM STORED LOCATION 2) MEANS OF TOOL AND SPARE CONTAINMENT AND RESTRAINT FOR EFFICIENT IFM OPERATIONS WITH MANIPULATOR	REQUIREMENTS IDENTIFIED ON "PREPARATION", RAS SHEET #______.

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: IPM - 2	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
CORRECTIVE MAINTENANCE	PROVIDE FOR: 1) BASIC DESIGN REQUIREMENTS FOR SPACECRAFT AS IDENTIFIED IN - IPM-2 "PREPARATION" DESIGN REQUIREMENTS #2 - IPM-2 "TROUBLESHOOTING AND DISASSEMBLY" DESIGN REQUIREMENTS #1 2) MEANS FOR PERFORMING, WITH THE MANIPULATOR, THE GENERAL TASK TYPES OF TORQUING, PUSH-PULL, IMPACTING, ETC. IN ORDER TO ACCOMPLISH THE BASIC CATEGORIES OF CORRECTIVE IFM (I, II, III, OR IV)	PROVIDE FOR: 1) TOOLS COMPATIBLE WITH MANIPULATOR END EFFECTOR OPERATIONS AND THE PLANNED WORKSITE/ EQUIPMENT CONFIGURATION 2) MEANS OF TOOL AND SPARE CONTAINMENT AND RESTRAINT FOR EFFICIENT IFM OPERATIONS WITH MANIPULATOR	1) PROCEDURES FOR TRAINING AND OPERATIONS 2) SEE REQUIREMENTS IDENTIFIED ON "PREPARATION", RAS SHEET #______

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: IPM - 2	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
RETURN TO OPERATIONAL STATUS	PROVIDE: 1) STOWAGE VOLUME FOR EQUIPMENT TO BE RETAINED 2) MAINTENANCE STATION AS REQUIRED FOR EXPERIMENTS AND/OR SPACECRAFT IFRU REPAIR	PROVIDE: MEANS OF RETURNING TOOLS, EQUIPMENT, IFRU, ETC. TO MOTHER VEHICLE STOWAGE VOLUME	REQUIREMENTS ARE IDENTIFIED IN IPM-2 "PREPARATIONS"

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
PREPARATION	PROVIDE FOR: 1) ACCESSIBLE STOWAGE VOLUME FOR - TOOLS - SPARES - TRANSLATION AIDS - WORKSITE STABILIZATION AIDS - SAFETY TETHERS - EQUIPMENT CONTAINMENT AND STABILIZATION DEVICES - PRESSURE SUIT AND LIFE SUPPORT EQUIPMENT - PROCEDURES - SYSTEMS DATA - WORKSITE ILLUMINATION DEVICES 2) AIRLOCK OPERATIONS (SEE DESIGN REQUIREMENTS FOR "EGRESS")	NO SPECIAL SUPPORT REQUIREMENTS	PROVIDE: 1) HIGH FIDELITY 1-G SIMULATOR, ZERO "G" SIMULATOR, AND NEUTRAL BUOYANCY SIMULATOR AS REQUIRED, CAPABLE OF SIMULATING EU-1 IFM 2) PROCEDURAL DATA FOR TRAINING AND OPERATIONS

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET		IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1		
IFM FUNCTION	**SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS**	**IFM SUPPORT REQ'S** - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	**TRAINING REQ'S** - TRAINING EQUIPMENT
EGRESS	PROVIDE: 1) AIRLOCK WITH ADEQUATE CLEARANCE THROUGH HATCHES FOR ALL CREW AND IFM EQUIPMENT TO BE CARRIED OR WORN	NO SPECIAL SUPPORT	USE OF SIMULATORS AS DEFINED IN EU-1 "PREPARATIONS"

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INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
TRANSLATION	PROVIDE FOR TRANSLATION AIDS USING EQUIPMENT SUCH AS: 1) VEHICLE INTERFACES WITH ATTACHABLE REMOVABLE HAND HOLDS AND FOOT RESTRAINTS 2) FIXED OR FIXED/RETRACTABLE HAND HOLDS PROVIDE STOWAGE AS REQUIRED FOR: o HAND-HELD MANEUVERING UNIT o ASTRONAUT MANEUVERING UNIT o "CHERRY PICKER" MODULE FOR USE WITH MANIPULATOR	PROVIDE: 1) TRANSLATION AIDS SUCH AS:- - TELESCOPING RODS - PORTABLE HAND HOLDS - PORTABLE FOOT RESTRAINTS AS REQUIRED 2) SAFETY LINES AND TETHERS 3) HAND-HELD MANEUVERING UNIT 4) ASTRONAUT MANEUVERING UNIT 5) "CHERRY PICKER" MODULE FOR USE WITH MANIPULATOR	USE OF SIMULATORS AS DEFINED IN EU-1 PREPARATIONS

PREPARED BY:	DATE:	IFM RAS CONTROL NUMBER:
APPROVED BY:	DATE:	REV. DATE: PAGE OF

INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
WORKSITE STABILIZATION	PROVIDE AS REQUIRED: 1) MEANS FOR SECURING BODY TETHERS, FOOT RESTRAINTS, TRANSLATION AIDS AND EQUIPMENT RESTRAINTS TO WORKSITE LOCATION 2) FOOT RESTRAINT CAPABILITY AT OR NEAR WORKSITE	PROVIDE: 1) BODY TETHERS 2) FOOT RESTRAINT AIDS 3) IFM EQUIPMENT TETHERS AND RESTRAINTS	USE OF SIMULATION AS DEFINED IN EU-1 PREPARATIONS

PREPARED BY:	DATE:	IFM RAS CONTROL NUMBER:
APPROVED BY:	DATE:	REV. DATE: PAGE OF

INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
ADDITIONAL TROUBLESHOOT-ING AND DIS-ASSEMBLY ("OPEN UP")	PROVIDE: 1) MEANS OF LOCATING AND GAINING ACCESS TO THE FAILED EQUIPMENT OR IFRU	PROVIDE: 1) TETHERS OR OTHER CONTAINMENT DEVICES FOR SPARES, TOOLS, ACCESS COVERS, ETC. 2) TOOLS FOR ACCESS-ING FAILED COMPO-NENTS (COMPATIBLE WITH PRESSURE SUIT AND ZERO "G") 3) ILLUMINATION FOR WORKSITE	1) HIGH FIDELITY MOCKUP 2) PROCEDURES FOR TRAINING AND OPERATIONS

PREPARED BY:	DATE:	IFM RAS CONTROL NUMBER:
APPROVED BY:	DATE:	REV. DATE: PAGE OF

INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
CORRECTIVE MAINTENANCE	PROVIDE: MEANS FOR PERFORMING THE GENERAL TASK TYPES, WHILE PRESSURE SUITED, OF TORQUING, PUSH-PULL, IMPACTING, ETC. IN ORDER TO ACCOMPLISH THE BASIC CATEGORIES OF CORRECTIVE IFM (I, II, III, OR IV)	PROVIDE FOR: 1) TOOLS COMPATIBLE WITH WORKSITE, EQUIPMENT, PRESSURE SUIT AND ZERO "G" 2) MEANS OF TOOL, SPARE SPARE AND EQUIPMENT CONTAINMENT AND RESTRAINT FOR EFFICIENT IFM OPERATIONS	1) PROCEDURES FOR TRAINING AND OPERATIONS 2) HIGH FIDELITY MOCKUP

PREPARED BY:	DATE:	IFM RAS CONTROL NUMBER:
APPROVED BY:	DATE:	REV. DATE: PAGE OF

INFLIGHT MAINTENANCE REQUIREMENTS ALLOCATION SHEET	BASIC SPACECRAFT - PAYLOAD CONFIG: ORBITER/SORTIE RAM WITH PALLET	IFM RAS SHEETS
CONTRACTOR:	IFM TYPE: EU - 1	

IFM FUNCTION	SPACECRAFT OR PAYLOAD DESIGN REQUIREMENTS	IFM SUPPORT REQ'S - TOOLS - LIFE SUPPORT EQUIP. - WORKSITE STAB. - SPARES - TRANSLATION AIDS - ILLUMINATION	TRAINING REQ'S - TRAINING EQUIPMENT
RETURN TO OPERATIONAL STATUS	PROVIDE: 1) STOWAGE VOLUME FOR EQUIPMENT TO BE RETAINED 2) MAINTENANCE STATION AS REQUIRED FOR EXPERIMENTS AND/OR SPACECRAFT IFRU REPAIR	PROVIDE: 1) TETHERS OR CONTAINMENT DEVICES FOR RETURN OF TOOLS, EQUIPMENT, ETC. TO MOTHER VEHICLE (THIS SHOULD NOT REQUIRE ADDITIONAL SUPPORT ITEMS IN MOST CASES)	REQUIREMENTS ARE INDICATED IN EU-1, "PREPARATIONS"

PREPARED BY:	DATE:	IFM RAS CONTROL NUMBER:
APPROVED BY:	DATE:	REV. DATE: PAGE OF

SC-M-0017

APPENDIX C

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JOHNSON SPACE CENTER

HOUSTON, TEXAS

PROPOSED

GENERAL SPECIFICATION,

INFLIGHT MAINTENANCE TASK AND SUPPORT

REQUIREMENTS ANALYSIS

I

FOREWORD

As inflight maintenance (IFM) of spacecraft and payloads must consider certain aspects not normally addressed in ground maintenance, the analytical process used to identify inflight maintenance tasks and associated support requirements requires a slightly different approach than that used for ground maintenance. This specification provides guidelines for analytical techniques and related documentation that takes into consideration the operational requirements unique to IFM. Furthermore, the technique uses the classical maintainability process for collecting much of the data required for effective analysis and provides definitive guidelines for documentation that is designed for efficient data processing usages for development of subsequent procedural and logistics report requirements.

This specification is to be used for NASA spacecraft and payloads committed to an inflight maintenance program and will normally be used for all long-term manned missions wherever system complexity, reliability and availability requirements so dictate.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 PURPOSE. The purpose of this specification is to provide the documentation to be used and the analytical process to be followed in defining crew operational requirements during the design phases for candidate inflight maintenance actions and the related support requirements for performance of these actions. Through application of this specification, engineering and management decisions can be made regarding candidate IFM tasks and related procedural, skill and support equipment requirements.

1.2 SCOPE. This specification is applicable to all NASA spacecraft programs involving inflight maintenance to be performed by crewmen on space vehicles. These vehicles include shuttle-type spacecraft, tugs, space stations, satellites and integrated payloads. Specifically, this specification provides for:

a) An analysis of potential inflight maintenance actions using maintainability analysis supporting data as baseline information.

b) Identification of the support equipment requirements for each task element along with appropriate stowage information.

c) Personnel identification of skill requirements, task times and and sequences.

d) Identification of hazards, special problems and considerations applicable to the task being performed.

1.3 APPLICABLE DOCUMENTS. The following documents (latest revisions) form a part of this specification to the extent specified herein.

SC-C-0009	General Specification Operations Location System, Crew Interfaces
SC-C-0011	General Specification, Stowage Management Process Requirements
SC-M-0016	General Specification, Inflight Maintenance Management Requirements

1.4 DEFINITIONS

a. Close Out - The process of returning an item to its initial configuration. This includes closing and securing access covers, doors, and equipment openings as well as removal of loose equipment used in performing or resulting from the maintenance action.

b. Egress - Crew operations related to movements through airlocks or hatches from interior to exterior compartments. During flight this will usually involve going from pressurized to unpressurized compartments or free space through airlocks. Engineering and operational concerns involve being able to move crewmen with support equipment in bulky space suits through the restricted airlock and hatch openings.

c. Gain Access - Opening up to an Inflight Replaceable Unit, either by direct crew actions while suited or unsuited or by manipulator operations through the opening of a spacecraft door or hatch, removal of an access cover or through opening of equipment access provisions.

d. Inflight Maintenance - All scheduled and unscheduled maintenance actions performed by the crew while in-orbit, translunar or transplanetary flight.

e. Ingress - Crew operations related to movements through airlocks or hatches from exterior to interior compartments. During flight this will usually involve going from unpressurized to pressurized compartments through airlocks.

f. Item - Used to denote any level of hardware assembly; i.e., system, segment of a system, subsystem, equipment component, part, etc.

g. Maintainability - A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period or time, when the maintenance is performed in accordance with prescribed procedures and resources.

h. Maintainability Analysis - The sequential development and review of data -- concurrent with, or preceding design development -- to aid in describing the optimum design characteristics of the equipment or system. The elements considered in the review are (1) quantitative requirements, (2) support resources, (3) cost, (4) operational objectives, and (5) safety. The results of the review are translated into criteria which are applied to the design process.

i. Maintenance - All actions necessary for retaining an item in or restoring it to a specified condition.

j. Preparation - All actions involved in preparing for inflight maintenance. This includes gathering tools, spares, support equipment, maintenance aids, procedural support documentation life support equipment, etc.

k. Return to Operational Status - The return of both the crewmen and the item to normal operational status.

l. Translation - Movement by a crewman from one location to another within the spacecraft or from locations remote to each other on the exterior surface of the vehicle or in free space. While in zero-g space environments the accomplishment of translation by a crewman will usually require some special aids such as handholds, maneuvering units, etc.

m. Verification and Test - Checkout of the repaired or replaced item to verify normal operations through use of spacecraft controls/displays, on-board built-in test equipment, special stowed test equipment, or through ground analysis.

n. Worksite Stabilization - Securing the crewman at the worksite during zero-g operations through the use of body and/or foot restraints to allow the crewman to perform effectively tasks involving applications by the crewman of forces of various types, such as torquing, push-pull, etc.

2.0 RESPONSIBILITIES. The National Aeronautics and Space Administration, Johnson Space Center (NASA JSC) shall insure compliance to this specification by contractors or designated government organizations for implementation of the inflight maintenance task and support requirements process defined herein for manned spacecraft programs. Requests for deviations, additions, or deletions to this specification shall be forwarded to the applicable NASA JSC spacecraft program office.

3.0 DESCRIPTION OF THE INFLIGHT MAINTENANCE TASK AND SUPPORT REQUIREMENTS ANALYSIS

3.1 GENERAL DESCRIPTION. This specification provides a method of defining the operational requirements for inflight maintenance tasks and the associated support requirements needed to accomplish these tasks. Furthermore, it defines the specific analytical and documentation requirements necessary for the Task and Support Requirements Analysis identified in the NASA JSC General Specification of Inflight Maintenance Management Requirements(SC-M-0016). The method presented here relies on existing maintainability and maintenance engineering techniques to determine the candidate inflight maintenance (IFM) tasks. Background data required for this task identification is discussed in paragraph 3.2. As a method of reducing program documentation requirements, no formal documentation is necessary for each trade-off study that is made but only those items selected for candidate IFM will be identified and further analyzed for operational feasibility. After a candidate IFM task is identified, analyses are required of the procedures to be used by the crew and of the related support requirements. This involves task descriptions by IFM task groups that identify operational segments having unique requirements. For each task, time estimates, personnel numbers and skill requirements and support equipment necessary for containment of items in zero-g, life support and safety tethering of personnel, tools, spares, special test equipment, etc. are identified. The detailed descriptions of this task and support requirements analytical technique are presented in paragraph 3.3.

The format and content of a standardized worksheet to document the analysis of tasks and related support equipment is specified. This basic worksheet is designed for computerized systems usage through the development of a data base and the generation of appropriate reports from this data base. Printouts such as Task/Tools Matrices, IFM Spares/Loose Equipment lists, IFM stowage list data, and personnel requirements may be obtained from judicious use of the data base. This inherent capability is discussed in paragraph 3.4. Furthermore, the prepared worksheet provides the baseline document for future procedures development.

It must be stressed that this method of IFM Task/Support Equipment analysis should be conducted in parallel with system design for manned spacecraft and payloads and should be updated as design and operational concepts change. This allows the user and his operational requirements to be given due consideration before system design rules out IFM.

3.2 DETERMINATION OF CANDIDATE IFM TASKS. The maintainability analysis process will assist in identifying candidate IFM tasks. The designer has five alternatives for providing the desired level of systems availability of a spacecraft or payload. These are:

a. To overdesign the system (component reliability)
b. To provide hardware redundancy

c. To accept system degradation
d. To return the system to earth, repair and recycle it

or

e. To provide an inflight maintenance capability

The maintainability analysis process will initially identify items that are candidates for inflight maintenance. After due consideration of IFM design criteria and system reliability and criticality, trade-off studies are made to ascertain if the initially identified candidate IFM items justify further analysis. Cost effectiveness must also be considered before making the decision in favor of IFM on a specific item. After the selection is made, the inflight task and support requirements analysis will be conducted for the selected candidate items.

3.3 PREPARATION OF THE INFLIGHT MAINTENANCE SUPPORT REQUIREMENTS ANALYSIS (ISRA) WORKSHEET. An ISRA worksheet will be prepared as per the standard format described in Figure 1 for each candidate IFM item and will be retained and maintained as the analytical record for those items considered for IFM. The format and content of this IFM Support Requirements Analysis (ISRA) worksheet structures the analysis and identifies the basic operational questions that should be answered for each candidate task and the necessary supporting resources required. The task descriptions on the worksheet are presented in sequential order by task groups. These groups are identified and coded in Table 1, Element 13. The purpose of this task grouping is to identify unique operational requirements associated with performing maintenance tasks in the zero-g, free-space environment. IFM tasks will not require all task grouping codes but the codes used will identify those operational functions that may appreciably impact the IFM tasks. This coding technique should be of assistance to the analyst by providing a systematic method for thorough and detailed examination of task and related support elements.

The ISRA worksheet is formatted so that the worksheet data may be readily transferred to IBM cards. The worksheet is essentially divided into four card formats (A, B, C and D). Card A contains worksheet elements one through seven; card B contains worksheet elements eight through 12; card C contains worksheet elements 13 through 21; and card D contains worksheet elements 13, 14 and 22 through 28. The task group/sequence elements (elements 13 and 14) on card C are identical to the task group/sequence elements on card D permitting correlation of the support equipment requirements, with the specific task element of the IFM candidate item requiring maintenance. The worksheet elements are identified by number and are defined in Table 1.

FIGURE 1. IFM SUPPORT REQ'S ANALYSIS WORKSHEET

(1) CONTROL NO. (2–8)

(2) TRANSFER NO (11–17)

(3) TASK ELEMENT NO. (18–29)

(4) IFM CANDIDATE ITEM (30–47)

(5) CONFIGURATION OR P/N (48–57)

(6) SUBSYSTEM/S. ELEM. (58–65)

(7) ORB (MOD./PAYLOAD) (66–69)

(8) SUMMARY IFM ACTION (18–35)

(9) TOTAL TASK ELAPSED TIME (36–39)

(10) IFM ITEM STATUS (40)

(11) IFM STATUS DATE (41–46)

(12) UNIT WEIGHT (47–52)

IFM SUPPORT REQ'S ANALYSIS WORKSHEET

REF. FMEA ____
CRITICALITY ____
MTBF ____
REPL. INT. ____ OP. HRS. / CAL (DAYS)
(29)

PREP. ____ DATE ____
INTEGR. ____
APPR. ____
REV. ____
PAGE ____ OF ____
(30)

(#'S) = ELEMENT #'S THAT ARE EXPLAINED IN TABLE I

TASK GROUP CODES

PR = PREP.
EG = EGRESS
XL = TRANSLATION
WK = WORKSITE STAB.
GA = GAIN ACCESS
MT = MAINT. PERFORMED
VE = VERIFICATION AND TEST
CL = CLOSE OUT
IN = INGRESS
RO = RETURN TO OPERATIONAL STATUS

(13) TASK GROUP	(14) SEQ.	(15) TASK DESCRIPTION	(16) ACCESS	(17) TASK TIME	(18) H/C	(19) SKILL	(20) IFM/CYCLE TY.	(21) IFM/CYCLE FREQ.

SUPPORT EQUIP. TYPE CODES

C = CONTAIN. DEVICES
I = ILLUM. AIDS
K = CHECK LISTS
L = LIFE SUPPORT
Q = SPEC. TEST EQUIP
R = RESTRAINTS, TETHERS
S = SPARES
T = TOOLS
W = WORKSITE STAB. AIDS
X = TRANS. AIDS

(13) TASK GROUP	(14) SEQ.	(22) SE. TY.	(23) QTY.	(24) SUPPORT EQUIPMENT REQ'S/NOMENCLATURE	(25) STOWAGE LIST ITEM #	(26) SUPPORT EQUIP. STOWED LOCATION	(27) IFM M ALTERTS/REMARKS	(28) IFM CODES

FOLDOUT FRAME 1

FOLDOUT FRAME 2

3.4 IFM LOGISTICS DOCUMENTATION CAPABILITY. As the information recorded on the ISRA worksheet is in a form suitable for development of a computerized data base and contains, for the candidate IFM item, data on support equipment type, quantity and specific equipment requirements. Reports and lists that can assist NASA Logistics in provisioning and preparation of the spacecraft and payloads may be generated from this data base. These reports should support the requirements of Integrated Logistics functions in development of stowage lists and in identifying related weights associated with IFM spares, tools and other support equipment. As a result, specific format and content requirements of these reports will be developed by contractor Maintainability and IFM organization functions and will be approved by the NASA IFM/Crew Interface Organization and by the NASA Integrated Logistics function. These logistics reports shall include but not be limited to:

a. Preliminary and baseline correlated lists of tasks and tool requirements
b. Preliminary and baseline correlated lists of tasks and spares and other IFM loose equipment requirements
c. Preliminary and baseline lists of IFM equipment in formats suitable for stowage list development usages

As the data base is updated through updating of the ISRA's, the logistics data will be updated and kept current to reflect the latest spacecraft and payload configuration.

TABLE 1

IFM SUPPORT REQUIREMENTS ANALYSIS DATA ELEMENTS

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
1. CONTROL NUMBER	CONTROL NO.	7 / (A/N)

DEFINITION - Alphanumeric coding to be used by the contractor for special sorts and data identification and control

2. TRANSFER NUMBER	TRANSFER NO.	7 / (A/N)

DEFINITION - Alphanumeric coding to be used by the integrator when a task or tasks must be moved from one worksheet to another

3. TASK ELEMENT NUMBER	TASK ELEMENT NO.	12 / (N)

DEFINITION - Coded number identifying task element in flight planning data base

4. IFM CANDIDATE ITEM	--	18 / (A)

DEFINITION - Nomenclature of inflight replaceable unit (IFRU) or equipment being serviced or inspected.

5. CONFIGURATION OR PART NUMBER	CONFIGURATION OR P/N	10 / (A/N)

DEFINITION - Part, or released drawing for configuration control, number

6. SUBSYSTEM/SYSTEM ELEMENT	SUBSYSTEM/ S.ELEM.	8 / (A/N)

DEFINITION - Subsystem or system element abbreviation and identification number

This identification system shall be developed by the contractor and submitted to NASA for approval.

Table 1 (continued)

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
7. ORBITER/MODULE/ PAYLOAD	ORB/MOD/ PAYLOAD	4 / (A/N)

DEFINITION - Designation of major vehicle, module or payload location of IFM candidate item

8. SUMMARY IFM ACTION	--	18 / (A)

DEFINITION - Description of the basic action to be performed (e.g., Replace, Repair, Inspect, Adjust, Calibrate, Refurbish, Troubleshoot, Functional test, Service, Verify, etc.)

9. TOTAL TASK ELAPSED TIME	--	4 / (A/N)

DEFINITION - Total of individual task times multiplied by their head count

The first two characters are numbers and the last two are MN (minutes) or HR (hours).

10. IFM ITEM STATUS	--	1 / (A)

DEFINITION - Status of candidate item in approval cycle

S: Submitted
I: In process
R: Returned for change
D: Disapproved
M: Modified
A: Approved

11. IFM STATUS DATE	--	6 / (N)

DEFINITION - DAY/MONTH/YEAR of IFM Item status reflected in element 10

12. UNIT WEIGHT	--	6 / (N)

DEFINITION - Weight of candidate item to nearest hundredth pound (e.g., 0 9 . 1 5 0)

Table 1 (continued)

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
13. TASK GROUP	--	2 / (A)

DEFINITION - Codes that identify the basic phases of operations in performing IFM tasks.

PR = Preparation
EG = Egress
XL = Translation
WK = Worksite stabilization
GA = Gain access
MT = Maintenance performed*
VE = Verification and test
CL = Close out
IN = Ingress
RO = Return to operational status

*The Summary IFM action will reflect the specific maintenance action performed such as Inspect, Service, Replace, Repair, etc.

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
14. SEQUENCE	SEQ.	2 / (N)

DEFINITION - Sequential task numbers that indicate action sequence and equate support equipment to specific task requirements.

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
15. TASK DESCRIPTION	--	30 / (A/N)

DEFINITION - Verbal description of specific task required to accomplish that part of the inflight maintenance required in the particular task group designated.

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
16. ACCESS	--	7 / (A/N)

DEFINITION - Coded identification of access, when required.

Table 1 (continued)

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
17. TASK TIME	--	4 / (A/N)

DEFINITION - Estimated elapsed time to nearest minute or hour for performing the task action identified in the task description.

MN = Minute(s)
HR = Hour(s)

The first two characters are allocated for numerical time (e.g., 32 MN = 32 minutes)

18. HEAD COUNT	H/C	1 / (N)

DEFINITION - Number of personnel required to accomplish task described in the Task Description.

19. SKILL	--	6 / (A/N)

DEFINITION - The first four characters are numbers designating a skill code for the discipline/subsystems involved. The fifth character is reserved for skill level required:

B = Basic skill level
I = Intermediate skill level
A = Advanced skill level

The sixth character is reserved for special skill requirements that are not discipline/subsystem oriented (e.g., M = manipulator expertise, E = EVA expertise)

20. IFM TYPE	TY.	1 / (A)

DEFINITION - Codes describing the general type of maintenance.

S = Scheduled
U = Unscheduled (Planned)
C = Contingency

Table 1 (continued)

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
21. IFM CYCLE FREQUENCY	FREQ.	4 / (A/N)

DEFINITION - The frequency of occurrence of the IFM task. The first two characters are reserved for numeric identification and the third and fourth characters are reserved for the measurement interval.

NUMERIC

01 = 1
65 = 65
3H = 300
6K = 6,000

MEASUREMENT INTERVAL

MN = Minute(s)
HR = Hour(s)
DY = Day(s)
MO = Month(s)
CY = Cycle(s)
VM = Mission(s)
WH = Whenever*

*Used for unscheduled and contingency maintenance.

22. SUPPORT EQUIPMENT TYPE	SE. TY.	1 / (A)

DEFINITION - Coded identification of type of support equipment.

C = Containment devices
I = Illumination aids
K = Check lists
L = Life support
Q = Special test equipment
R = Restraints, tethers
S = Spares
T = Tools
W = Worksite stabilization aids
X = Translation aids

Table 1 (continued)

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
23. QUANTITY	QTY.	2 / (N)

DEFINITION - Quantity of support equipment required.

24. SUPPORT EQUIPMENT REQUIREMENTS OR NOMENCLATURE	--	28 / (A)

DEFINITION - Requirements for support equipment (e.g., tool carrier) or specific nomenclature of equipment, if known.

25. STOWAGE LIST ITEM NUMBER	--	6 / (A/N)

DEFINITION - The basic control number by which each stowed item is identified in the stowage list.

26. SUPPORT EQUIPMENT STOWED LOCATION	--	8 / (A/N)

DEFINITION - The location of the stowed support equipment using the NASA JSC location coding system but limited to six (6) identifying characters and a dash.

EXAMPLES

2	W	-	1	2	6	C

or

C	V	-	A	3	6	

or

4	H	-	B	L	C	B

Table 1 (continued)

WORKSHEET ELEMENT	ABBREV.	FIELD SIZE / (MODE)
27. IFM M ALERTS/ REMARKS	--	18 / (A/N)

DEFINITION - Inflight maintenance design problems; hazardous operations; design or operational concerns; or applicable remarks.

28. IFM CODES	--	2 / (A)

DEFINITION - Coded entry identifying problem of concern or remark.

HZ = Hazardous operation
SO = Series operation
CL = Clearance required
PZ = Pressurization operations
DP = Depressurization operations
Etc.

29. ENGINEERING REFERENCE DATA JUSTIFYING CANDIDATE ITEM SELECTION

DEFINITION - This data element is not included within the ISRA data base but is included on the worksheet to provide reference data documenting the rationale for the selection of a particular item of equipment as candidate for IFM tasks. This data includes the Failure Modes Effects Analysis (FMEA) reference number and the criticality of the effects of a failure of a candidate item. In addition, predictions of the mean-time between failures (MTBF) are included in this worksheet element along with the predicted time between replacement of the item.

30. WORKSHEET APPROVAL DATA.

DEFINITION - This worksheet element is not included within the ISRA data base but is included on the worksheet for worksheet approval signatures and control elements such as revision indication and date.

APPENDIX D

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